Abstract

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Characterization and Cost-Analysis of Drinking Water Quality Monitoring in India and Jordan

(Under the direction of Dr. Jamie Bartram)

Water quality monitoring programs aim to support provision of safe drinking water through informed decision making at three levels: policy makers, water providers, and communities or end users. Little guidance or published evidence exists on best monitoring practices for low resource settings, such as in developing countries. The purpose of this research was to characterize current monitoring practices in India and Jordan, and analyze the costs of monitoring programs. Characterization included institutional mapping of the water sector and describing monitoring programs. Cost analysis included marginal costs; test materials, laboratory and sampling staff labor, and sample transportation. Focus was on monitoring of biological parameters (e.g. *E.coli*, coliforms, and H_2S Presence-Absence). Data collection involved mixed qualitative and quantitative methods. The different approaches to monitoring drinking water and the principal components of cost in three states in India and in Jordan are presented. The study indicates that there is potential for substantive optimization of monitoring programs as currently practiced particularly in low population density areas.

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1.0 Introduction

1.1 Significance and scale of drinking water issues in developing countries

Many people around the world lack access to safe drinking water, directly resulting in higher disease rates, and indirectly lowering their quality of life through economic wellbeing, missed educational opportunities, and time taken from work. In 2010 87% of the world's population had access to an improved water source as defined by the World Health Organization (WHO), leaving a population of 884 million without access (WHO & UNICEF 2010). This 884 million is concentrated in developing countries, especially in sub-Saharan Africa and South and Southeast Asia (ibid). The United Nations recognized the importance of access to safe drinking water in 2000 by including it in the Millennium Development Goals, and in 2010 by declaring that water is a human right.

Diarrheal disease is responsible for 4.8% of the global disease burden (2.2 million annual deaths), but is responsible for 7.2% of disease burden in developing countries, in which children under 5 years of age suffer the most (WHO 2004, Pruss-Ustun & Corvalan 2006). Of this diarrheal disease, an estimated 94% is attributable to environmental factors such as unsafe drinking-water and poor sanitation and hygiene; highlighting the need for these exposure pathways to be addressed (Pruss-Ustun & Corvalan 2006).

The WHO and UNICEF category of an "improved water source" includes household connections, public standpipes, boreholes, protected dug wells, protected springs, and rainwater collection. Improved water sources as described by the WHO and UNICEF are not necessarily free of disease-causing pathogens. Access to an improved water source alone is only part of the picture; the quality of water being consumed must also be considered.

1.2 The role of water quality

The connection between water and health has been known throughout recorded history, and John Snow's epidemiological study of the 1849 cholera outbreak in London shed light on the direct connection between drinking water and infectious disease. Since then, many disease outbreaks have been attributed to waterborne diseases spread through urban and rural drinking water systems in both developed (Hrudey et al. 2006) and developing countries (Ford 1999). Diarrheal diseases caused by environmental exposures are contracted through direct or indirect contact with or ingestion of food or water contaminated with disease causing pathogens. Waterborne pathogens contribute to background diarrheal disease rates, and additionally can cause disease outbreaks. Waterborne pathogens that cause diarrheal diseases include large variety of bacteria, viruses, and protozoa which can be time consuming and costly to isolate and identify in drinking water if they are identifiable at all. These pathogens enter water through fecal contamination from animals and humans. *Escherichia coli* (*E.coli*) has been accepted as the best biological indicator of water safety since 1890 as it is present in all mammalian feces; since then many methods for identifying *E.coli* in water have been developed (Edberg et al. 2000). Total coliforms and thermotolerant coliforms are also widely used as indicators of microbiological quality of drinking water, especially for drinking water post-treatment.

There is strong evidence that access to safe drinking water is a necessary step in lowering background diarrheal disease rates, although evaluating what portion of the disease burden could be averted though water related interventions is difficult. Evidence for the impact or relation of interventions in water supply and quality on public health outcomes is mixed, with different studies reporting no association to strong association. A meta-analysis of twelve studies that evaluated the health effects of interventions targeting water quality found a 39% reduction in disease post-intervention (Fewtrell, et al. 2005). This meta-analysis also found point-of-use interventions to be more effective than water source interventions, and interventions in rural settings to be more effective than interventions in urban or peri-urban settings. Sanitation and hygiene interventions were also slightly more effective at reducing diarrheal disease than were water supply and quality interventions.

A more recent meta-analysis reached similar conclusions; that interventions targeted at improving drinking water quality are effective at reducing diarrheal disease in developing countries (Clasen, et al. 2009). Clasen, et al. (2009) also point out that these studies are generally short term (evaluation less than one year following the intervention), and there is significant heterogeneity between studies (type of intervention, setting, target population). Because these studies are generally short term, they do not measure the sustainability of interventions. The heterogeneity between studies explains the variation and uncertainty of the results when interventions are compared side by side. Pruss et al. (2002) outline the many pathways for exposure to human and animal excreta (and associated pathogens) (**Figure 1**). These exposure pathways are complex and vary across different settings, which is a possible explanation for the variation between results seen by meta-analyses.

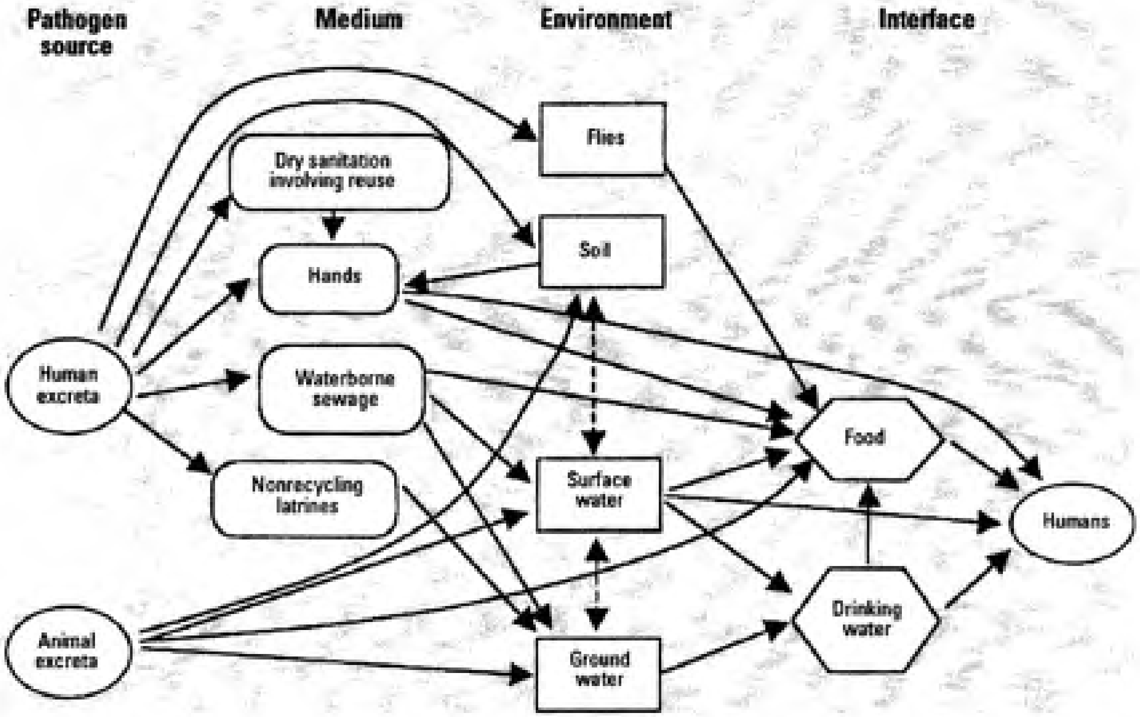

Figure 1: Transmission pathways of fecal-oral disease. Taken from Pruss et al. (2002).

Access to safe drinking water can prevent disease outbreaks, and lower diarrheal disease burden. The exact importance of water quality will vary across settings, as the relative importance of different disease transmission pathways is context specific. Delivering drinking water free of disease-causing pathogens depends on control of sources of contamination, treating source water to an acceptable quality, and ensuring that water is not contaminated between treatment and point-of-use. This involves water quality management targeted at risk management.

1.3 Water quality management

Risk management frameworks are a comprehensive approach to ensuring safe water supply. Some of the first frameworks for ensuring safe drinking water were developed based on the Hazard Analysis and Critical Control Point (HACCP) framework for food safety assurance (Havelaar 1994; Barry, et al. 1998; Deere and Davison 1998; Gray and Morain 2000). The HACCP framework gives seven steps for food safety: hazard analysis, identification of control points, limits for control points, monitoring requirements, corrective actions, record keeping, and procedures for ensuring the HACCP system is working. The WHO refined this through the 1990s into a framework for drinking-water safety, which is composed of health based targets, system assessment, operational monitoring, management plans, and independent surveillance (WHO 2004). The three middle components (system assessment, operational monitoring, and management plans) comprise a system-specific Water Safety Plan (WSP) (WHO 2008).

1.4 Water Quality Monitoring

The WSP framework and earlier WHO publications specify that both operational monitoring and independent surveillance should take place, which include testing for indicators of fecal contamination. Operational monitoring is in place to inform decision making and corrective actions regarding the control measures (e.g. source protection, water treatment). Surveillance of drinking water quality engages an independent third party in oversight of water supply, with the specific mandate for protection of public health (WHO 2008). This study focused on water quality operational monitoring and surveillance (from here forth collectively called "monitoring"), which are necessary components of a water quality management framework.

Drinking water quality monitoring forms an essential component of water quality management for safe water provision. In resource poor settings, there is often limited capacity to upgrade or even maintain water systems. International recommendations and standards for drinking water quality monitoring programs exist: the WHO publishes the most comprehensive guidelines for water quality monitoring, and the International Standards Organization (ISO) publishes the most widely used standard methods for sampling and testing of drinking water. The WHO "Guidelines for Drinking Water Quality" (WHO 2008) specifically recognize the central importance of microbial parameters in monitoring, as they pose the most common and widespread health risks. Additionally, monitoring should be comprehensive by including urban *and* rural water supplies, as rural supplies contribute disproportionately to unsafe water in most countries. The WHO guidelines acknowledge that legislation and standards need to account for the costs of drinking water quality surveillance and control. There is a variety of methods to assess microbiological quality of drinking water, but the most widely accepted (and regulated) parameters are total and thermotolerant coliform, and *E.coli*.

Little published literature exists on evidence of the efficiency or effectiveness of monitoring as practiced, particularly in settings where limited resources inhibit the ability to comprehensively monitor water supply. One paper draws on case studies in Uganda and Peru to investigate how to conduct effective surveillance of water supply in urban settings, where surveillance includes monitoring activities and sanitary inspections, and evaluations of cost and reliability of supply (Howard & Bartram 2005). This study found that surveillance should be used to support public health considerations first, but also to support incremental improvements in water supply by improving targeting of interventions. A more recent study (which formed the beginning of this project) looked at institutional mapping of the organizations and agencies involved in drinking water quality monitoring nine developing countries (Rahman et al. 2010). This study concluded that urban piped supplies are generally well monitored, while lack of capacity often leads to little to no monitoring in informal settlements and rural settings. Additionally, it found that surveillance monitoring occurs both as direct testing of water supply, and as auditing of water supplier based operational monitoring, the latter approach is often adopted in an effort to increase cost efficiency. While the first study discusses effective monitoring, and the second study discusses efficiency of monitoring, neither approaches these questions quantitatively.

1.5 The Importance of Information

Environmental water quality monitoring (i.e. monitoring of lakes, streams, and other natural water resources) is much more thoroughly covered in the literature than is drinking water quality monitoring. An early study and review of environmental water quality monitoring practices concluded that the central function of water quality monitoring is to support water quality management and decision making, and should be designed with this in mind (Wald, et al. 1986). This study states that *status quo* monitoring programs are "data rich but information poor," meaning that there is a missing link between water quality testing and informed decision making. The solution to this, they propose, is an emphasis on testing to support management, including looking at how information supports decision making, and who should receive what information, in what format, and when. A more recent paper about the development of an environmental monitoring framework for Mexico reached similar conclusions (Biswas, et al. 1997), which are be applicable to drinking water. This study asserted that water quality management depends on good monitoring, but monitoring is often prohibitively expensive and does not focus on the right parameters, locations, or sampling times. Water quality monitoring programs should be designed to promptly and cost-effectively deliver relevant information to decision makers, as otherwise they are generating useless data and not supporting water quality management. Both studies emphasize that the connection between generating data and informing decision making is important.

Huang and Zia (2001) write that "reliable information is essential for designing effective water-quality-management systems." Bartram (1996) described four categories for the linkage of water quality information to actions: overview assessment, regional and local management and operations, enforcement of standards, and community management. Jalan and Somnathan (2009) looked at the impact that awareness of and education on environmental health risks have on the demand for environmental quality. They found that if households understand the risks of pathogens in drinking water, they were more likely to treat their water. A study in Bangladesh looked at the effect of green/red well labeling according to arsenic concentrations partnered with education on the risks of arsenic in drinking water, and found that 60% of study participants did change their behavior in response to information on water quality (Malgosia, et al. 2007). Bartram's categories include actions ranging from policy creation and amendment to enforcement to operational management of water supply. Limited evidence exists for the effective links between information and policy or regulation, though the studies mentioned give experimental evidence on the valuable link between information and individual and household decision making.

There is an abundance of evidence and support for the importance of safe drinking water for public health; from documentation of waterborne disease outbreaks to more recent studies on endemic diarrheal disease. Water quality monitoring as a component of water quality management is necessary for the provision of safe drinking water. Previous research studies have shown that monitoring is often an expensive endeavor, but is ineffective if information generated is not linked to action, awareness, or decision making. For water quality monitoring to be both comprehensive and effective in resource-limited settings, there needs to be evidence for how to improve efficiency of monitoring programs.

This research project investigates current monitoring practices from multiple settings within India and Jordan. This culminates in an analysis of current monitoring costs in comparison with what monitoring would cost if it were comprehensive.

2.0 Research objectives:

1. To characterize how water quality monitoring is carried out by government agencies and central authorities in contrasting settings in three states in India and in Jordan, with a focus on how sampling and testing is prescribed to be conducted as compared to sampling and testing in actual practice.
2. To estimate the overall costs associated with current monitoring programs in three states in India and in Jordan.

3.0 Methods

This research project involved multiple stages. Initial work included reviewing published and gray literature on water quality monitoring and on the water sector in general to frame the research questions. This was followed by collaboration with the Aquaya Institute on mapping the interactions and responsibilities of institutions involved in drinking water quality monitoring in nine countries (presented in **Appendix A**). A sampling method termed clustering was then used to determine how representative the nine countries were of the developing world, and to select two additional countries for greater representation and for a more detailed monitoring characterization and cost analysis. Four data collectors on this project then traveled to Ghana for 10 days to pilot data collection methods and further refine the project scope. In depth data collection took place during summer 2010 in three states in India and in Jordan. Finally, follow up qualitative and quantitative analysis of monitoring in India and Jordan took place between September 2010 and March 2011. Shown in **Figure 2** below is a flow chart describing all activities included in this research project.

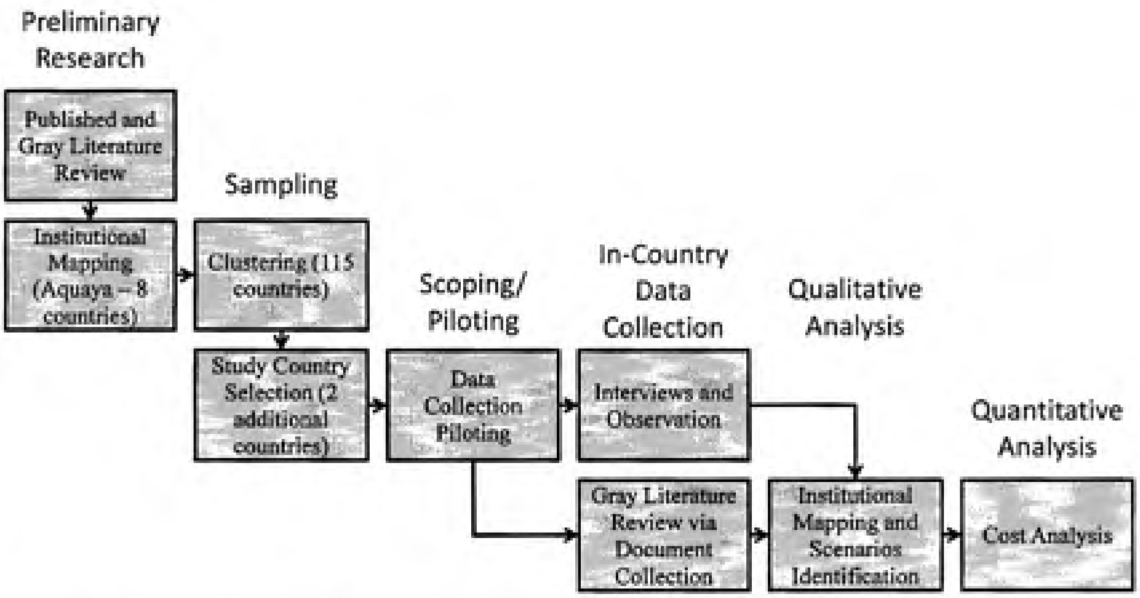

Figure 2: Project approach flow chart.

3.1 Preliminary Research

3.1.1 Published and Gray Literature Review

Peer reviewed literature and gray literature were reviewed at the beginning of the project to gain an understanding of how monitoring typically occurs. As most of the available published or documented information on water quality monitoring is not located in peer-reviewed journals; literature review consisted primarily of review of national water policies, water quality standards, regulations, agency and utility operating frameworks, and laboratory manuals for a country. These documents were located and obtained using Google scholar, Google search engine, government and utility websites, and email correspondence with individuals within the water sector in each country. This gray literature review was used to understand basic monitoring approaches in study countries (i.e. how monitoring is prescribed to occur).

3.1.2 Institutional Mapping

The Aquaya Institute characterized institutional frameworks and water quality monitoring roles and responsibilities in nine countries: Bolivia, Brazil, Cambodia, Ecuador, Lao PDR, Malawi, Peru, Sri Lanka, and Viet Nam (Rahman et al. 2010, see **Appendix A**). Characterization of institutional frameworks involved water sector mapping supported by the University of North Carolina at Chapel Hill (UNC). Institutional framework maps depict organization's roles at three levels: 1) drinking water policy development; 2) surveillance and regulatory compliance assessment; and 3) service provision and operational monitoring. These maps are based on published reports, gray literature, policy documents and interviews with relevant water sector actors carried out by the Aquaya Institute and UNC as an activity of the Aquatest Research and Development Program, an initiative to design water quality management tools that are optimized for resource-poor settings (Rahman 2010). Although the institutional maps include the major groups involved in drinking water provision and management, they do not cover in full detail institutions and activities at every administrative level.

Each country's institutional map displays the primary institutions involved in drinking water delivery and water quality testing for both urban and rural areas. The ministries responsible for overall sector policies and strategies, and for developing water quality standards, are illustrated in the top row. The institutions responsible for water quality surveillance and regulation of water quality compliance are listed in the central row. The institutions responsible for service provision are specified in the third row. The maps also identify the institutions responsible for operational and surveillance testing activities. See **Appendix A** for the publication containing the nine institutional maps generated by the Aquaya Institute.

3.2 Sampling

Characterizing monitoring practices for every developing country was not feasible given the scope and timeframe for this project. Thus, a sample of developing countries representing a variety of approaches to drinking water quality monitoring was needed in order to generate insights regarding water quality monitoring across the broad range of settings that exist throughout the developing world. A sample of developing countries was selected for characterization to represent a range of approaches to monitoring.

Developing countries were grouped into distinct clusters, to enable stratified sampling. Existing country sampling approaches applied to the water sector for grouping countries have focused on factors such as geography and economic indicators. The Millennium Development Goals country grouping is geography based (countries are additionally grouped into developed and developing) (http://www.unicef.org/statistics/index_step1.php). The WHO country grouping is geography and epidemiology based (http://www.who.int/quantifying_ehimpacts/global/ebdcountgroup/en/index.html). The UNICEF country grouping is geography based (although industrialized countries are separated into their own group) (http://www.unicef.org/infobycountry/index.html). The World Bank has three systems for grouping countries: by geographic region, by income (gross national income per capita), and by lending category (determined based on income group and credit rating) (data.worldbank.org). While all of these country groupings have some merit for their respective applications, water quality monitoring practices do not necessarily follow geographic boundaries or economics.

For this project, countries were therefore grouped based on similarity across a range of indicators. These indicators were chosen on their relation to water quality monitoring, as well as data availability for a large set of countries. These indicators were roughly categorized into determinants of the water sector and status of the water sector, although there is no exact line between the two categories as some of the determinants can be affected by water quality monitoring and management.

3.2.1 Selection Criteria

Water Sector Determinants

1. Gross domestic product per capita ($/capita)
2. Government Effectiveness (normalized World Bank index)
3. Percent of total population living on less than $1 per day in international dollars (%)
4. Water and sanitation aid per capita ($, from Organizations for Economic Cooperation and Development-Development Cooperation Directorate (OECD) member states and multilaterals)
5. Percent of total population completing tertiary education (%)
6. Percent of female population completing secondary education (%)

Water Sector Status

1. Percent of rural population with access to a non-piped improved water source (%)
2. Percent of urban population with access to a non-piped improved water source (%)
3. Percent of rural population with access to piped water (%)
4. Percent of urban population with access to piped water (%)
5. Child (under 5) diarrhea morbidity (total cases/year/1000 children)

Determinants affect the ability of government and water suppliers in a country to implement effective and comprehensive monitoring. Gross domestic product relates to the available economic resources for monitoring. Government effectiveness (defined by the World Bank as the involvement and support a government puts towards public services) relates to government commitment to public services such as drinking water safety and its monitoring. Percentage of a population below $1 per day is a measure of poverty in a country, and relates to the distribution of public services within a country. Water and sanitation aid relates to the amount of foreign capital directly invested into the water sector. Tertiary education relates to the availability of professionals qualified to work on water quality monitoring and management. Female secondary education relates to community and households awareness to the importance of safe drinking water.

Outcomes relate to the quality and coverage of water supply in a country. The first four are indicators of access to improved water supply based on the WHO and UNICEF categories (improved water supply includes household connections, boreholes, protected dug wells, protected springs, or rainwater collection). Child diarrheal morbidity relates to exposure to water-borne pathogens.

3.2.2 Normalization

The indicators used to group countries are on different scales and have different units; for example percentages range from 0 to 100; government effectiveness ranges from -2.5 to 2.5; and GDP is a positive dollar value up to ~$100,000 per capita per year. For cluster analysis, all indicators were normalized (converted to a standard deviation of 1 and a mean of 0). This also gives equal weight to each indicator, and near-equal weight to the determinants category and the outcomes category.

3.2.3 Clustering Process

Clustering was conducted using the STATA 10.1 software package. The process used is average-linkage clustering, also known as unweighted pair group method with arithmetic mean. This process uses a stepwise or dendrogram approach to clustering countries. The clustering starts with each country forming its own cluster. At each step the two closest clusters are combined, leaving one less cluster in the set. Euclidian distance (sum of the squared difference of each indicator) is used as the measure of difference between clusters. The distance between clusters is calculated as the average distance between all countries in those clusters. For the sake of illustration, **Figure 3** shows the average linkage clustering method if only two indicators were used (two dimensions). The distance between any two clusters is the average of ALL links between them. As 11 indicators were used for this analysis, graphical representation is not possible. This hierarchical clustering method is often represented with a dendrogram. This allows for any number of clusters to be chosen for a set from 1 cluster to n clusters, where n is the number of individual countries.

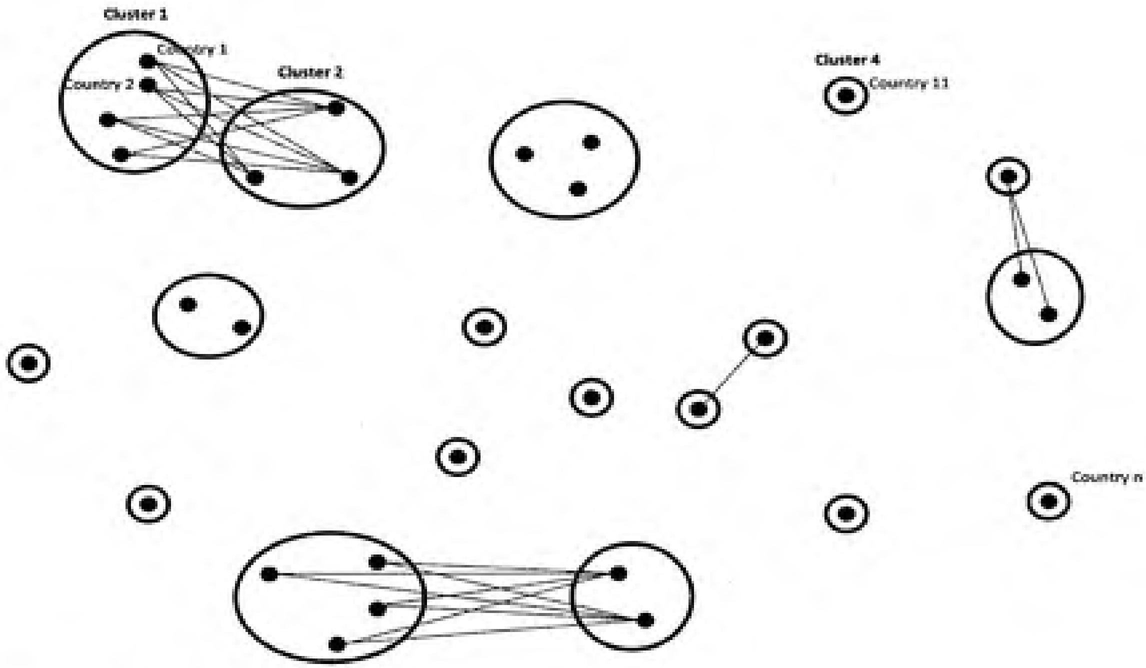

Figure 3: Average linkage method for cluster analysis

3.2.4 Cluster Analysis

The cluster analysis included 115 of the 205 recognized countries and territories—those remaining after all countries and territories with missing data were removed, with a few exceptions as follows. For the indicator "percent of population living below $1 per day," if a high income country from Europe or North America was missing data, a value of 0 was entered manually. For the indicator "water and sanitation aid," if any country was missing data, a value of 0 was entered manually (as the OECD reports all recipients of governmental aid, this is not an assumption). Any adjustments were done before data was normalized. The 115 countries in the analysis include countries from every region of the world, and both developed and developing countries. Omitted countries are primarily territories and small island states for which complete data was not available. A full list of countries included is presented in **Appendix B**.

The dendrogram approach allows a final result with any number of clusters, with each combination viewable. The dendrogram in **Figure 4** shows the clustering steps from 40 clusters down to 1. The nine clusters shown boxed in black in **Table 1** were chosen for country sampling. Clusters containing predominantly developed countries and clusters with a relatively small total population were omitted. The work by Rahman et al. (2010) that preceded this study involved institutional mapping for the nine countries, eight of which are highlighted in light gray in **Table 1** (Sri Lanka was excluded as it was missing education data). For the research described here, two additional countries were selected for institutional mapping and a detailed cost analysis. These two countries (India and Jordan, highlighted in dark gray) were selected to represent two additional clusters not covered by Rahman et al (2010). The institutional mapping paper can be found in **Appendix A**.

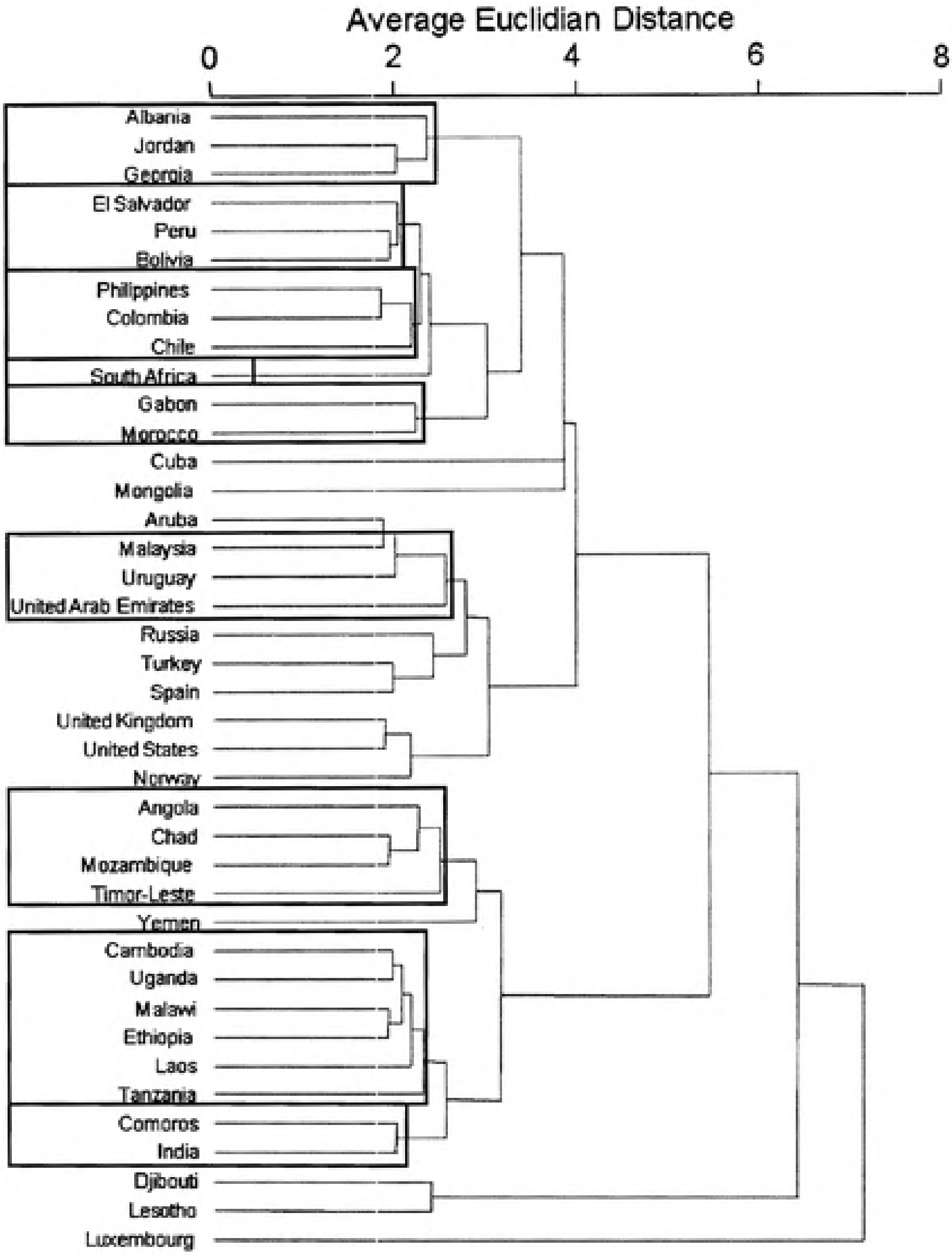

Figure 4: Dendrogram of country clustering from 40 clusters to one cluster.[1]

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[1] Each country name represents a cluster of countries, with a total of 115 countries represented.

Table 1: Country clusters used for country selection. Study countries chosen to represent their cluster s are highlighted.

1
Albania
[redacted]
Panama
Armenia
Guyana
Costa Rica
Georgia

2
Algeria
El Salvador
Paraguay
Brazil
Peru
Azerbaijan
Tajikistan
Honduras
Nicaragua
Bolivia

3
Thailand
Argentina
Philippines
Kyrgyzstan
Ecuador
Colombia
China
Egypt
Dominican Republic
Tunisia
Trinidad and Tobago
Mexico
Guatemala
Jamaica
Chile

4
Uzbekistan
Suriname
Namibia
VietNam
Botswana
South Africa

5
Gabon
Senegal
Morocco

6
Cuba
Mongolia
Aruba
Cyprus
Malaysia
Uruguay

7
Angola
Chad
Liberia
Nigeria
Madagascar
Mozambique
Timor-Leste

8
Cambodia
Kenya
Bangladesh
Cameroon
Benin
Malawi
Guinea
Burkina Faso
Mali
Uganda
Zambia
Congo
Niger
Ethiopia
Papua New Guinea
Swaziland
Laos
DR Congo
Guinea-Bissau
Togo
Sierra Leone
Tanzania
Burundi
Rwanda

9
Comoros
Gambia
Ghana
Nepal
[redacted]
Cote d'Ivoire
Pakistan

3.3 Piloting and Scoping: Ghana

Individuals who would be carrying out data collection through field work took part in a piloting trip to Ghana. Ghana was chosen for reasons of practicality; the researcher had prior work experience and contacts within the water sector in Ghana. The purpose of the piloting trip was both to trial different methods for collecting the necessary data for this project, and for researchers to gain experience in interviewing a range of stakeholders from the water sector. See **Appendix C** for a list of the data requirements for this project as presented to data collectors prior to piloting work in Ghana.

The piloting trip included focus groups, interviews, observation of laboratories, and collection of documents not available online. Focus groups and interviews were carried out with individuals representing government agencies, private utilities, and non-profits involved in water supply and water quality monitoring. Within the major organizations involved (Ghana Water Company Limited, and the Community Water and Sanitation Agency) individuals from multiple levels were interviewed (including central office quality managers, regional water quality managers, and laboratory staff). Different question formats and orders were trialed, and discussed afterwards by the research team. See **Appendix D** for the resulting interview guidelines as presented to data collectors prior to field work during summer 2010.

3.4 In Country Data Collection

Two data collectors spent three months total in India (Wagner and Thapa), and one data collector spent one month in Jordan (Crocker) conducting interviews. Both collected relevant documents and observed practice. Data collectors were chosen based on previous international experience, knowledge of the water sector, and knowledge of relevant culture and language. Prior to field work in India and Jordan, two of the three data collectors spent 10 days in Ghana piloting data collection methods and refining the scope of the project.

3.4.1 Interviews

The majority of data used for this research project was collected through interviews with individuals from the water sector in each study country. Interviews were carried out both from a range of organizations, and also from a range of levels within an organization. For organizations implementing monitoring (i.e. collecting or testing samples themselves), multiple interviews were pursued. This was necessary because water quality managers, laboratory managers, and laboratory technicians have different knowledge of the activities of an organization. Multiple interviews within an organization also allowed verification of information received during interviews. Water quality managers and similar interviewees were asked for broad information such as the responsibilities of their organization, and how they interact with other organizations. Laboratory managers and laboratory technicians were asked for more specific information such as how many samples are collected each day, how many tests are run each day, and what type of test is performed.

A "top-down" approach to scheduling interviews was used. Individuals at a higher level and working for central government agencies were approached first. Early interviewees were asked for contacts from other organizations and within their organization that could be approached for additional interviews.

The piloting work in Ghana resulted in an interview approach that involved first asking a qualitative question targeted at returning information on certain data needs. Closed quantitative questions were then asked to follow up on any aspects of the data need that were not addressed. Thus the approach and the data needs addressed were standardized for all interviews, while the exact questions varied from one interview to the next. The interview guidelines (laid out as an example interview) are shown in **Appendix D**.

3.4.2 Observation

When possible, observation of sampling and testing practices was carried out by the researchers. This allowed for verification of information obtained during interviews or extracted from literature and documents. Observation of sampling trips allowed for estimation of how much time is spent sampling each day and how many samples are collected on a sampling trip. Observation of testing allowed for an estimation of how many samples a laboratory technician can process in a day, and also what test is being used when multiple are available.

3.4.3 Gray Literature Review

During interviews and laboratory visits, additional gray literature (as described in Section 3.1.1) was identified and collected whenever possible. Prescribed monitoring practice was characterized primarily through information from gray literature obtained during field work in study countries. This included the prior mentioned water policies, water quality standards, regulations, agency and utility operating frameworks, and laboratory manuals; but also included water quality results, reports between organizations, and alerts and advisories when contamination was detected.

3.5 Qualitative Analysis

Qualitative analysis consisted of institutional mapping and descriptions of roles and responsibilities within the water sector (described in Section 3.1.2), and describing monitoring scenarios. Monitoring practice in study countries was categorized into "monitoring scenarios" in order to facilitate cost analysis. A monitoring scenario was defined as any distinct approach to monitoring. Differences in approach to frequency of sampling, approach to collecting and transporting samples, test methods used, and reporting all distinguish between scenarios. As costing parameters and reporting mechanisms were to be collected for each scenario, literature review and early interviews were used to identify regularly occurring monitoring scenarios in a study country.

3.6 Quantitative Analysis

Cost analysis consisted of first quantifying the transportation of water samples, testing of water samples, and labor required for sampling and testing for each scenario. These quantitative parameters were then multiplied by unit costs to arrive at a cost estimate for each scenario. Cost analysis focused on marginal costs, thus capital costs were excluded. Laboratory maintenance, labor not associated directly with microbial monitoring, and legislation and standards development were not included in cost analysis; as it was assumed that these are activities that would exist regardless of microbial monitoring.

3.6.1 Parameterization

Quantitative parameters used in the cost analysis are shown in **Table 2**. The data collected varies in format, from water quality standards to interviewee responses to direct observation of testing. The approach to cost analysis is show in **Figure 5**. A list of the methods and assumptions used to convert data into value estimates used in the cost analysis is shown in **Appendix E.**

The costs of test materials for each scenario depends on the type of test used and the annual number of tests completed. The costs associated with labor vary for positions with different salaries or pay scales, and by the percent of time each employee dedicates to monitoring in a given year. The costs associated with transportation can be estimated from the distance traveled to collect samples or from the amount of time spent traveling. Each component of cost shown in **Table 2** is not necessarily able to be collected directly from interviews or literature.

Table 2: Cost parameters and categories

Test Material Costs	**Labor Costs**	**Transportation Costs**
Number of tests per year	Hours of laboratory staff time	Distance traveled
Type of test used	Cost per hour of laboratory staff time	Cost per mile
Cost per test	Hours of sampling staff time	Time spent traveling
	Cost per hour of sampling staff time	Cost per hour
		Cost per sample collected

3.6.2 Scaling

For most scenarios, quantitative data was collected on the above parameters for one region of a country, or for one laboratory out of many. In order to estimate the cost for an entire country or state, these parameters were scaled to a country- or state-wide level. Parameters were scaled using population, number of laboratories, or number of tests, depending on the type of information being scaled. For example, if an interviewee stated that each lab processed an average number of tests per year, this information would be scaled using the number of laboratories. A full list of methods and assumptions made for scaling parameters to a country or state level is presented in **Appendix E**.

3.6.3 Unit Costs

In order to convert scaled parameters into a cost estimate, unit costs for test materials, staff labor, and transportation were needed. Kromoredjo and Fujioka (1991) evaluated three test methods for microbiological quality of drinking water in a study in Indonesia; Colilert, Laurel-Tryptose Broth + 4-methylumbelliferyl-ß-D-glucuronide (LTB+MUG), and H_2S test strips. All three tests were conducted in an MPN fashion, using five tubes. The costs for these tests are presented in this study as \$6.50, \$1.62, and \$0.62 respectively. The \$1.62 estimate is used in this study as the cost for multiple tube tests and the \$0.62 is used as the cost for H_2S P-A tests. Labor costs and transportation costs are calculated differently for India and Jordan. In India, samplers and laboratory technicians are reimbursed per sample collected and test conducted. For Jordan cost analyses, cost per mile was estimated using the American Automobile Association method, and labor costs were taken from the Jordan 2008 census.

The unit costs for each scenario, as well as the method used to estimate them are presented in **Appendix E.**

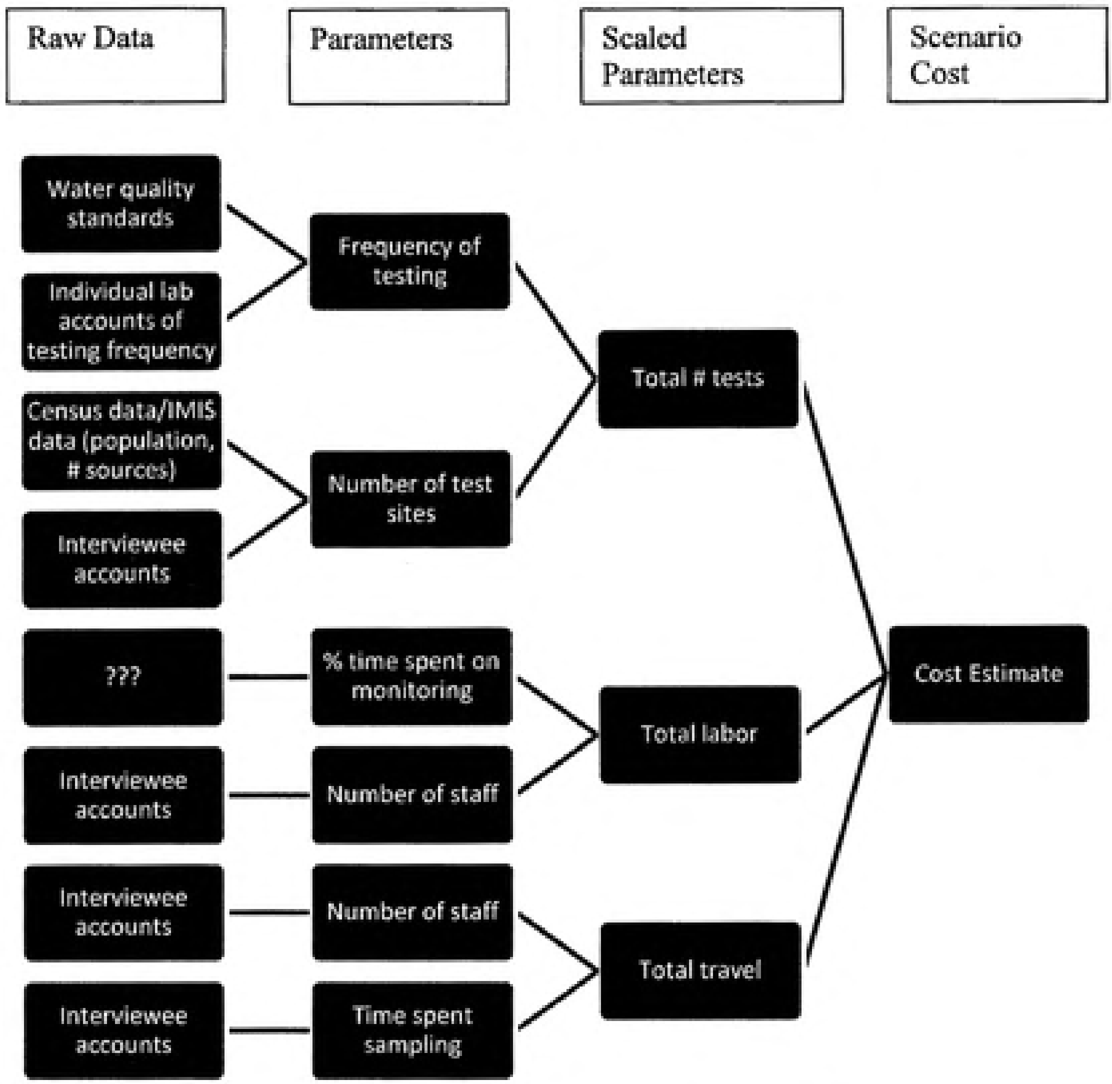

Figure 5: Schematic of process for converting raw data into a cost estimate.

4.0 Results and Discussion

Basic characteristics for the three study states in India and for Jordan are presented in **Table 3**. Throughout the Results and Discussion sections, costs are reported in current US Dollars. This does not accurately represent the *value* of investments in monitoring, as the strength of currency varies from country to country. **Table 3** gives the ratio of USD to international dollars (taken from the International Monetary Fund database). One dollar in India is valued at $2.72, while in Jordan it is valued at $1.74.

Table 3: Basic statistics for study countries

Country	Population	Access to an Improved Drinking Water Source (%)	Population Living in a Rural Setting (%)	GDP per capita (USD)	Int'l Dollars to USD Ratio[3]
India[1]					2.72
Uttar Pradesh	166,198,000	80.7	79.2	323	
West Bengal	80,176,000	72.6	72.0	618	
Maharashtra	96,879,000	71.9	57.6	905	
Jordan[2]	5,729,000	98.0	17.0	3,466	1.74

[1]www.censusindia.net, [2]unstats.un.org, [3]converted from imf.org GDP values in 2007

The following subsections are organized by country and state. For country and state, presentation of results starts with map of the water sector, followed by narrative descriptions of the main organizations involved in drinking water quality monitoring and their roles. This is followed by descriptions of monitoring scenarios, a cost analysis, and a discussion. Finally, costs for each state or country are normalized and presented in an inter-state and inter-country comparative table and figure. Results presented in each country section represent estimated current practice for each scenario. Actual practice will vary slightly from the results presented, as estimated current practice is extrapolated from data collected from interviews in a variety of settings and is not a precise measure of practice across Jordan or each state in India.

In the study countries government agencies prescribe the monitoring programs that government organizations and water suppliers should follow. Monitoring as actually practiced can vary significantly from the theoretical approach described by the government. For this reason, cost analysis results are reported both as monitoring is *prescribed* to occur, and as *estimated* actual practice.

4.1 India National Profile

In India, the water sector is primarily managed at the state level rather than the national level, so three states were chosen for characterization to gain insight into the variation in practice between states. Uttar Pradesh, West Bengal, and Maharashtra were chosen using the clustering approach described in Section 3.2. They are a combined one-third of the total population of India. Furthermore, these states represent a range of water access, percent of the population that lives in a rural setting, and GDP per capita; and are broadly representative of the overall national situation. In the three states characterized, distinct monitoring scenarios exist for rural point sources, and for piped supplies in large and small urban settings. Thus scenarios are presented by setting in each India state section, with notes on any exceptions encountered.

The organizations at the national level involved in creating water quality monitoring guidelines are shown in **Figure 6**. The national government's interaction with the state governments is also shown in **Figure 6**.

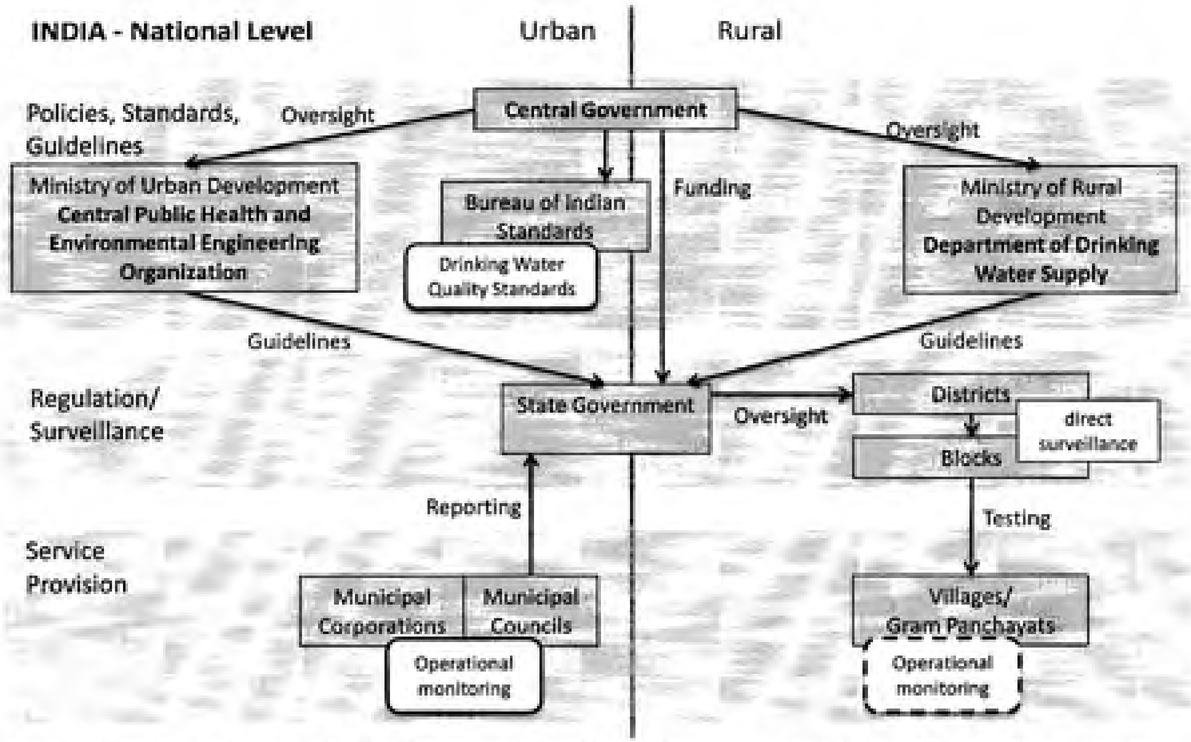

Figure 6: Water sector in India [at the national level] as it relates to drinking water quality monitoring

4.1.1 Key National Level Organizations:

As the role of the national government of India is in setting guidelines and providing funding to the states, the below organizations do not directly participate in monitoring activities. Nonetheless, they are very influential in the way monitoring occurs within each state.

The **Bureau of Indian Standards** (BIS) sets standards for drinking water quality monitoring, including how sampling should be conducted, how testing should be conducted and which tests should be used, and what final drinking water quality should be. The standard pertaining to finished water quality is the IS-10500:1983. The standard pertaining to sampling and microbiological testing is IS-1622:1981. The BIS standard for microbiological testing describes two test methods—membrane filtration for total coliform and *E.coli* and multiple tube for total coliform and thermotolerant coliform—though the H_2S P-A test is used widely for rural monitoring throughout India as well.

The **Ministry of Rural Development** (MoRD) is one of the two ministries in the central government that is responsible for creating recommendations and frameworks for implementation for drinking water supply and monitoring programs in all states, as well as for funding the state governments' plans. The MoRD is specifically concerned with rural water supply and quality monitoring. The MoRD does not have legal jurisdiction over practices in the individual states, but they are the most influential organization in relation to rural water supply and monitoring due to their role as the primary funder of state level projects.

The **Department of Drinking Water Supply** (DDWS) is part of the MoRD and is responsible for the aforementioned macro-level policy generation. The main guideline published by the DDWS in regards to drinking water quality monitoring is the "National Rural Drinking Water Programme: Framework for Implementation 2009-2012."

The **Ministry of Urban Development** (MoUD) is parallel to the MoRD, and is responsible for creating macro-level recommendations and frameworks for implementation for urban water supply and monitoring programs at the state level, as well as funding the state governments' plans. The MoUD does not create legally binding frameworks, but is influential due to its role as the primary funder of urban water projects.

The **Central Public Health Environmental Engineering Organization** (CPHEEO) is the department within MoUD responsible for creating the technical recommendations for the MoUD. The main guideline published by the CPHEEO in regards to drinking water quality monitoring is the "Manual on Water Treatment and Supply," chapter 15.

4.2 Uttar Pradesh

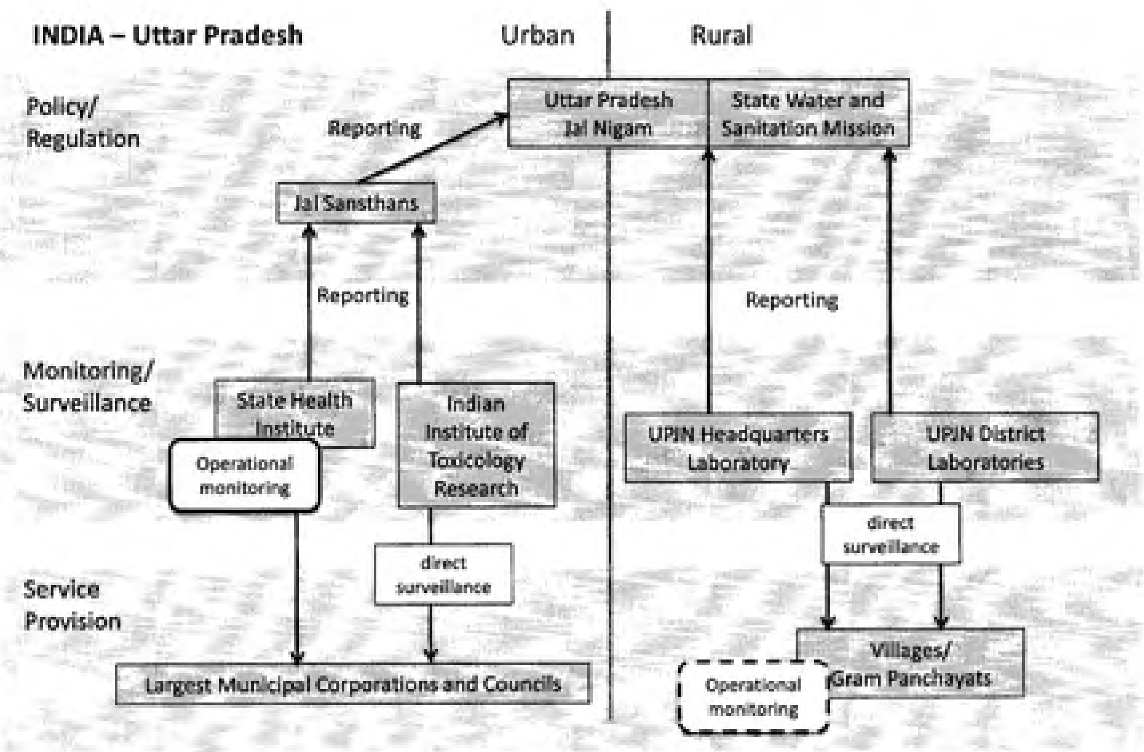

Figure 7: Water sector map for Uttar Pradesh as it relates to drinking water quality monitoring

4.2.1 Key Organizations

The **gram panchayats** (GPs) are the smallest unit of local government within a state and are composed of varying numbers of villages. Wide-scale use of field testing kits is being piloted in Uttar Pradesh, and will rely heavily on community participation through the gram panchayats.

The **Indian Institute of Toxicology Research** (IITR) operates one of two laboratories in Uttar Pradesh that test drinking water samples from the Jal Sansthans in the state. While the State Health Institute processes most drinking water samples, the IITR occasionally performs quality control between laboratories by cross-checking samples sent to the SHI and reporting the test results back to the Jal Sansthans.

Jal Sansthans (JS) act as water boards in five of the largest cities in Uttar Pradesh each have their own Jal Sansthan. The Jal Sansthans are responsible for treatment, distribution, and monitoring of drinking water in these cities.

The **State Health Institute** (SHI) is one of the two laboratories that tests drinking water samples from the Jal Sansthans in the state. The SHI is responsible for testing daily samples, and reports results directly to the Jal Sansthans, the Uttar Pradesh Jal Nigam, the

Chief Medical Officer of the state, and the appropriate Municipal Council daily. Monthly reports are also sent from the SHI to the state government of UP.

The **Uttar Pradesh Jal Nigam** (UPJN) is responsible for oversight of drinking water and sanitation in UP. The UPJN follows the guidelines and manuals created by the MoRD and the MoUD, and does not create any water policies or standards on their own. The UPJN is responsible for building water-related infrastructure, but transfers water projects to the local Jal Sansthan or Panchayati Raj Institution for operation and maintenance. There are two branches of water quality monitoring in the UPJN: departmental and community-based. The UPJN departmental based water quality monitoring involves district laboratories which collect and test rural drinking water samples daily. Test results from the district laboratories are aggregated and analyzed at the central UPJN office. The community-based water quality monitoring program involves Village Water and Sanitation Committees testing drinking water using field kits, but is relatively new and has not been fully effective.

Village Water and Sanitation Committees (VWSCs) are five person teams made up of individuals from a gram panchayat who are responsible for testing rural water supplies using H_2S P-A field kits. Some VWSCs are already operating, and additional VWSC workers are being recruited and trained to expand rural testing.

Water Works (WWs) exist in 18 small cities and towns, where they manage, operate, and maintain drinking water supply for these towns. None of the 18 WWs test for microbiological indicators, but they occasionally send water samples to UPJN laboratories for microbiological testing.

4.2.2 Drinking water quality monitoring scenarios in Uttar Pradesh

There are four monitoring scenarios occurring in Uttar Pradesh that include microbiological testing; two each for rural water supplies and large urban water supplies. Small urban water supplies are not monitored for microbiological parameters. Additionally, the central UPJN laboratory is supposed to conduct duplicate testing on 5% of samples brought to laboratories in the state, but this monitoring is not occurring in practice.

Large Urban Monitoring

In five of the largest cities in Uttar Pradesh, the Jal Sansthans partner with the State Health Institute to perform water quality monitoring. These five cities are: Allahabad, Agra, Kanpur, Lucknow, and Varanasi; serving a total population of 8.5 million. There is one central laboratory run by the State Health Institute, which is supposed to test 10-15 drinking water samples each day from each of the cities. These samples are tested for total coliforms and *E.coli* using either membrane filtration or multiple tube method. The results of these tests are reported from the State Health Institute laboratory to the appropriate Jal Sansthan and Municipal Corporation, as well as to the UPJN and the Chief Medical Officer. This monitoring is used primarily for operational purposes, such as identifying contamination events.

Small Urban Monitoring

There are a total of 661 small cities and towns in Uttar Pradesh, for a total population of 25.9 million people. Interviewees reported that drinking water in small cities and towns is not monitored for biological parameters.

Community-Based Rural Monitoring

The UPJN promotes the decentralized, community-based water quality monitoring program which is outlined in the *National Rural Drinking Water Programme: Framework for Implementation* created by the DDWS.

The UPJN oversees monitoring conducted by VWSCs. For each of 52,000 gram panchayats there is a five-person VWSC team. The five person teams were trained through the State Water and Sanitation Mission, and were later provided with field testing kits from the UPJN. The VWSCs monitor the 2.2 million rural hand pumps in Uttar Pradesh. Each VWSC is responsible for testing every source in their area twice a year for evidence of bacteriological contamination using H_2S P-A tests. The MoRD suggests that one test be conducted before the monsoons and the other during, as more fecal contamination typically occurs during the rainy season.

The goal of the gram panchayat team is to test two times a year and have the data from the field testing kits communicated to the block district officer in report form and then a compiled report from the block sent to the UPJN district level. At the district level, the test results are entered into the online Integrated Management Information System (IMIS), which is housed in the DDWS. This data is to be collected for every gram panchayat in India and is supposed to be used to inform policy creation and modification at the state level and guideline creation and modification at the central level.

When there is a water quality issue that is identified at the gram panchayat level and communicated to the UPJN, typical suggestions from the UPJN would be that the gram panchayat chlorinate, repair any broken platforms, and then retest. However, the sole responsibility for responding to water quality issues falls to the gram panchayat. Interviewees indicated that very little testing is actually occurring in this scenario, and even fewer test results are being reported or used.

Laboratory-Based Rural Monitoring

The UPJN refers to the *Implementation Manual on National Rural Water Quality Monitoring and Surveillance Programme* created by the DDWS in 2006 for surveillance monitoring of rural water schemes.

The UPJN oversees the JN district laboratories on testing the microbiological quality of rural drinking water sources (2.2 million handpumps). Most district have one laboratory, and those without share a neighboring district laboratory for testing. Laboratories test for total coliform and *E.coli* using the multiple tube method, although six to seven laboratories in the district are equipped to perform membrane filtration testing. Interviewees indicated that roughly 5% of rural drinking water sources are tested once each year by the district laboratories.

The district laboratory reports test results to the central UPJN office for review. If there is any indication of contamination, the UPJN will collect a water sample from that source to be retested. If the second sample shows contamination, the UPJN would request a remedy plan from the district. The UPJN also sends data to the government of UP, to the state ministries and other state level organizations involved in drinking water.

Scenarios Not Characterized

The IITR laboratory collects drinking water samples from the five largest cities in Uttar Pradesh to be tested for total and thermotolerant coliform using the multiple tube method, to check the drinking water quality and as quality control on the SHI laboratory. This monitoring scenario is a relatively small contribution to total costs, and thus was not characterized or included in cost analysis. The UPJN is supposed to conduct duplicate testing on 5% of rural drinking water samples that are brought to district laboratories at a central laboratory for quality control purposes, though interviewees indicated this testing is not occurring.

4.2.3 Cost Analysis for Uttar Pradesh

The estimated cost of monitoring associated with each scenario in Uttar Pradesh is presented in **Table 4**. Testing costs represent the cost of materials associated with the test method for each scenario. Labor costs represent the cost of the time sampling staff and laboratory staff spend on microbiological monitoring. Sampling cost represents the cost associated with transportation to sampling sites and back to the laboratory where samples are tested. The target population presented in **Table 4** is not equal to the population covered by a monitoring scenario; for every scenario covered population would in reality be lower than the target population. The target rural population is the entire rural population, although in reality monitoring activities focus on boreholes, thus unimproved rural water supplies are not included. The target population for urban monitoring is all urban residents, although in reality monitoring activities focus on piped supplies, and non-piped urban water supplies are not monitored. This is the case for target populations presented for all three states in India and for Jordan. The exact covered population is not available data and therefore is not presented here. UN-Habitat presents some information on piped versus unpiped urban water supply, but the information is not comprehensive and is not available at a state level for India. The UNICEF & WHO Joint Monitoring Program presents data on improved versus unimproved rural water supply, but again the information is not available at a state level for India.

Table 4: Costs for Uttar Pradesh monitoring scenarios

	Rural - Op	Rural - Surv	Small urban	Large Urban
Target population	131,283,554	131,283,554	25,902,670	8,538,593
Actual practice				
# tests per year	12,223	110,000	0	546
testing cost	$12,223	$110,000	$0	$1,234
labor cost	$0	$121,000	$0	$710
sampling cost	$0	$294,151	$0	$1,460
total cost	$12,223	$525,151	$0	$3,404
Prescribed practice				
# tests per year	4,400,000	220,000	57,240	10,284
testing cost	$4,400,000	$220,000	$129,362	$23,242
labor cost	$0	$242,000	$74,412	$13,369
sampling cost	$0	$588,302	$153,065	$27,500
total cost	$4,400,000	$1,050,302	$356,840	$64,111

4.2.4 Uttar Pradesh Discussion

Community-based monitoring for rural areas is occurring in very few of the intended gram panchayats in Uttar Pradesh. There are many potential causes for this such as lack of financial incentive, faulty training of teams, or expired or incomplete field kits. Interviewees most consistently pointed to one explanation; field kits are not reaching the intended recipients. The State Water and Sanitation Mission trained community teams, and at a separate time and location the Uttar Pradesh Jal Nigam distributed field kits to community based teams.

In Uttar Pradesh, small cities and towns are monitored for residual chlorine, but are *not* monitored for microbiological parameters. A large portion of the rural and small urban population in Uttar Pradesh consuming drinking water that is not monitored for fecal contamination.

Duplicate monitoring is supposed to be occurring in Uttar Pradesh through the UPJN district laboratories for rural water supply and through the IITR laboratory for urban monitoring, although in practice both community-based and laboratory based rural monitoring combined do not reach all rural water supplies. Additionally, for all of the scenarios detected in Uttar Pradesh the UPJN, which is part of the state government, is supposed to receive water quality reports as a way to audit monitoring activities. These duplicate monitoring scenarios for rural settings, and state government reporting for urban monitoring are designed to act as checks on water quality.

4.3 West Bengal

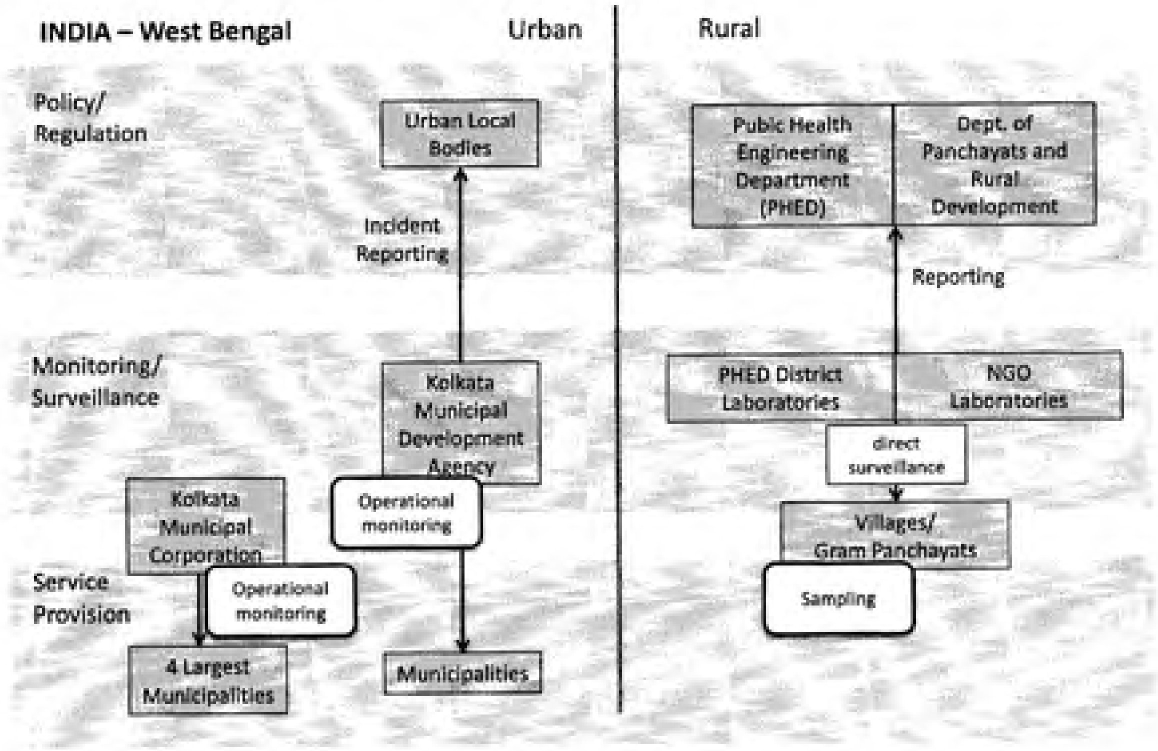

Figure 8: Water sector map for West Bengal as it relates to drinking water quality monitoring

4.3.1 Key Organizations:

Block laboratories (BLs) are managed in two ways in West Bengal: those managed by NGOs (80) and those managed by the PHED (34). There is very little difference between the two laboratory types in practice, though they have different management and PHED laboratories are in general newer than NGO laboratories. All of the samples collected by the gram panchayat facilitators are tested at the block laboratories. There is generally one block laboratory for every three blocks. All block laboratories use the multiple tube method to test drinking water samples.

The **Kolkata Municipal Corporation** (KMC) is the water supplier for the city of Kolkata. It is responsible for treating, supplying and monitoring the drinking water for Kolkata.

The **Kolkata Metropolitan Development Agency** (KMDA) is responsible for monitoring drinking water treatment plants, but is not directly responsible for monitoring the quality of water once it enters the distribution system.

The **Department of Panchayats and Rural Development** (P&RD) is responsible for training the water sample collectors (gram panchayat facilitators), organizing payments from the state to the Zilla Parishad, maintaining the P&RD water quality online database, and analyzing the data in the P&RD database.

The **Public Health Engineering Department** (PHED) is responsible for providing drinking water to rural areas, overseeing the functioning of the block level water testing laboratories, maintaining the PHED water quality online database, and analyzing the data in the PHED database.

Zilla Parishads (ZPs) are the district level local government body responsible for moving funds from the state level organizations to the block level laboratories, and for paying the gram panchayat facilitators who collect water samples.

4.3.2 Drinking water quality monitoring scenarios in West Bengal

There are three monitoring scenarios occurring in West Bengal that include microbiological testing; one each for rural water supplies, large urban water supplies, and small urban water supplies.

Large Urban Monitoring

The Municipal Corporations for the four largest cities in West Bengal monitor drinking water quality for those cities. The four cities are Assansol, Howrah, Kolkata, and Silguri; a total population of 14.7 million. All of these cities have designated water treatment plants and water quality laboratories, although with the exception of the two laboratories in Kolkata, these laboratories conduct residual chlorine testing in place of fecal indicators. The Kolkata laboratories test for total coliform, thermotolerant coliform, and *E.coli* using either multiple tube method or membrane filtration method. The number of tests performed each day depends on the population of the city, and is documented in detail in the Central Public Health & Environmental Engineering Organization (CPHEEO) manual on Water Treatment and Supply, chapter 15. Monitoring conducted by the Municipal Corporations is primarily used to identify contamination for immediate response. The reports generated from routine plant testing are used primarily for internal purposes; aside from being sent to the Plant Engineer, reports are sent once a month and in times of contamination to the Director of Health Services and are also sent to the KMC in case of contamination.

Small Urban Monitoring

There are four laboratories that monitor the drinking water for small cities and towns in West Bengal: the KMDA central laboratory, the All India Institute of Hygiene and Public Health

(AIIHPH) laboratory, the State Pollution Control Board (SPCB) laboratory, and the Jadavpur University laboratory. These small cities and towns make up 39 Urban Local Bodies, and have a combined estimated population of 7.7 million people. Samples are collected four times a year from both the treatment plants and the distribution system for the 236 small urban areas. The samples are tested at four independent laboratories. Samples collected from plants are tested for total coliform and *E.coli*, while samples from the distribution system are tested just for chlorine residual. It is unclear from interviews what test method is used. Test results are reported to corresponding urban local body (ULB), and to the KMDA if a test result indicates contamination.

Laboratory-Based Rural Monitoring

The PHED oversees monitoring of rural drinking water quality in West Bengal. Water Samples are collected from each water source one to two times per year by gram panchayat facilitators, who deliver them to one of the 80 NGO run block laboratories and 35 PHED run block laboratories for testing. Each gram panchayat has one gram panchayat facilitator who is responsible for collecting and transporting water quality samples. These samples are tested for total coliform and *E.coli* using the multiple tube method. The test results are reported from the laboratories to the gram panchayats, which in turn report results to the Panchayat Samiti, PHED, and ZP. The ZP reports results to the SWSC. This monitoring is primarily conducted to notify gram panchayat facilitators when contamination is found in rural water supplies.

Scenarios Not Characterized

Five percent of water samples collected for the "rural surveillance monitoring scenario" in West Bengal are supposed to be brought to regional laboratories for duplicate testing, but interview accounts indicated this scenario is not yet occurring.

4.3.3 Cost Analysis for West Bengal

The estimated cost of monitoring associated with each scenario in West Bengal is presented in **Table 5**. Testing costs represent the cost of materials associated with the test method for each scenario. Labor costs represent the cost of the time sampling staff and laboratory staff spend on microbiological monitoring. Sampling cost represents the cost associated with transportation to sampling sites and back to the laboratory where samples are tested.

Table 5: Costs for West Bengal monitoring scenarios

	Rural	**Small urban**	**Large Urban**
Target population	57,748,818	7,681,811	14,745,440
Actual practice			
# tests per year	103,894	944	11,129
testing cost	$168,308	$1,529	$18,029
labor cost	$155,841	$1,227	$22,903
sampling cost	$277,816	$5,286	$19,476
total cost	$668,457	$8,647	$81,330
Prescribed practice			
# tests per year	940,536	19,171	17,712
testing cost	$1,523,668	$31,057	$28,693
labor cost	$1,410,804	$24,922	$36,451
sampling cost	$2,515,024	$107,358	$30,996
total cost	$5,449,497	$163,337	$96,140

4.3.4 West Bengal Discussion

In West Bengal monitoring for microbiological parameters occurs in all three settings. For rural water supply and small city and town water supply, expenditures are far below the target. Many rural water supplies are not monitored at all for microbiological parameters, while small city and town water supplies are monitored at a very low frequency; four times per year. The number of tests processed each year for large urban water supplies in West Bengal as currently practiced is near the target. There is no duplication of monitoring for any setting in West Bengal; each water supply falls only into one scenario. Although there is no third party conducting testing for water supply in West Bengal, results are supposed to be reported to the state government for auditing-based surveillance. Monitoring of small cities and towns is used only internally and is not reported to outside organizations.

4.4 Maharashtra

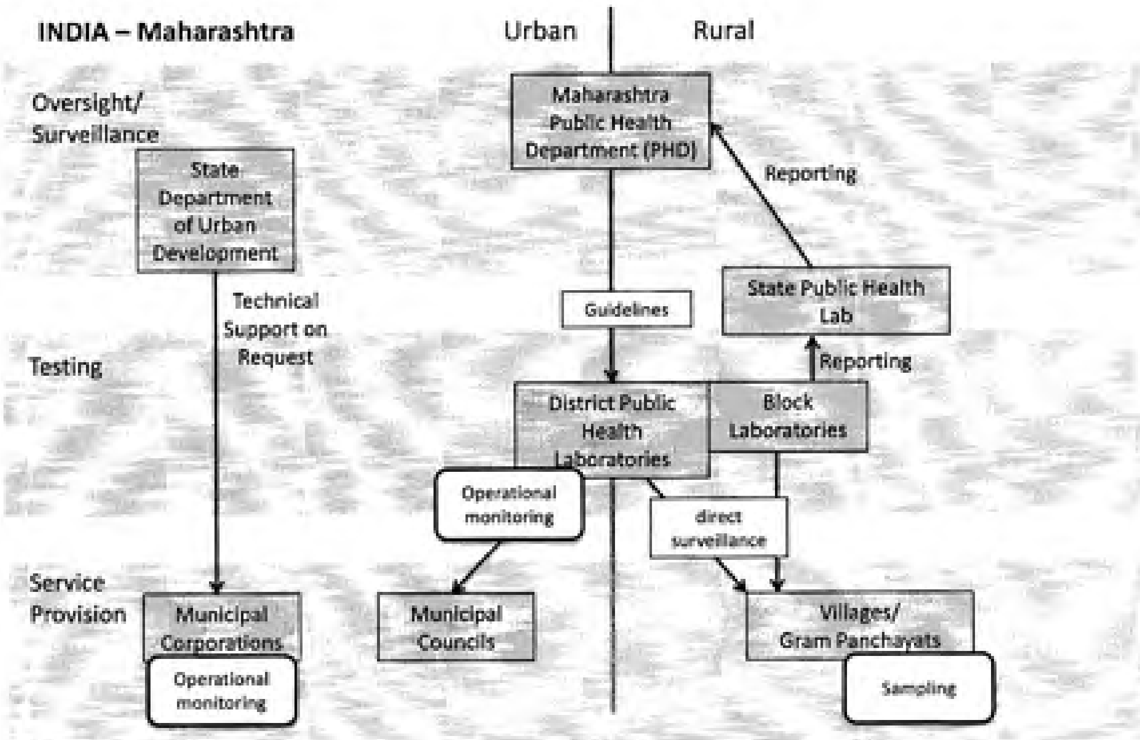

Figure 9: Water sector map for Maharashtra as it relates to drinking water quality monitoring

4.4.1 Key Organizations:

There are 23 **Municipal Corporations** (MCorps) in Maharashtra. Each large city has its own MCorp, which is a semi-autonomous large city government. The Municipal Corporations are responsible for drinking water distribution and for operation and maintenance of drinking water supply. The six largest Municipal Corporations (Mumbai, New Mumbai, Pimpri, Pune, Solapur, and Thane) perform their own water quality monitoring and operate their own water quality laboratories, while the other 17 Municipal Corporations use the public health laboratories for drinking water quality monitoring.

Municipal Councils (MCouncils) are semi-autonomous small city governments. There are 226 small cities and large towns which have Municipal Councils in Maharashtra, which manage drinking water provision and carry out operation and maintenance of drinking water supply. All of these organizations utilize the public health laboratories for drinking water quality monitoring.

The **Public Health Department** (PHD) is in charge of the network of public health laboratories, which perform the majority of water quality testing in Maharashtra. The PHD oversees the State Public Health Laboratory, the District Public Health Laboratories and the Rural Hospital Laboratories (also referred to as block level laboratories, or mini-laboratories). The PHD also oversees the Multi-Purpose Workers (MPWs) who collect the majority of water quality samples in the rural areas of the state. The PHD is involved in policy modification, and the final decisions regarding policy modifications must be approved by the Directorate of Health Services in the Department of Public Health.

There is one **District Public Health Laboratory** (DPHL) per district, which is responsible for testing water quality samples and uploading data to the HMIS.

One to **two rural hospital laboratories** (RHLs) exist for each block. Rural hospitals are generally equipped with a mini-laboratory which is responsible for testing water quality samples from their geographic area, and for reporting the results to the DPHL and the village the sample was collected from.

The **State Public Health Laboratory** (SPHL), located in Pune, is responsible for testing water quality samples, overseeing district public health laboratories, collecting data from the six largest Municipal Corporations, and compiling and entering water quality data from the entire state onto the Health Management Information System (HMIS). The SPHL develops the laboratory manual that is used in the district public health laboratories and the rural hospital mini-laboratories. The SPHL also oversees the quality control of testing material preparation. For example, SPHL tests the quality of the H_2S P-A medium before it is used.

4.4.2 Drinking water quality monitoring scenarios in Maharashtra

There are three monitoring scenarios occurring in Maharashtra that include microbiological testing; one each for rural water supplies, large urban water supplies, and small urban water supplies. The current approach to monitoring in Maharashtra is transitioning to a system that involves direct surveillance rather than audit-based surveillance.

Large Urban Monitoring

Municipal Corporations operate treatment plants with dedicated water quality laboratories in the six largest cities in Maharashtra (Mumbai, New Mumbai, Pimpri, Pune, Solapur, and Thane), although Mumbai operates two treatment plant laboratories. The combined population of these six cities is 18.4 million people. These laboratories test water at the treatment plants once daily for total coliform and *E.coli* using the multiple tube method. The number of tests performed each day depends on the population of the city, and is documented in detail in the Central Public Health & Environmental Engineering Organization (CPHEEO) manual on Water Treatment and Supply, chapter 15. Each Municipal Corporation is autonomous but they report their testing results monthly to the state public health laboratory for audit-based surveillance purposes.

Small Urban Monitoring

There are 17 smaller Municipal Corporations and 226 Municipal Councils that utilize the 35 district public health laboratories for monitoring their drinking water quality. The combined population of these 241 cities and towns is 18.6 million people. The district public health laboratories test water samples from these cities and towns for total coliform and *E.coli* using the multiple tube method. The number of tests performed each day depends on the population of the city, and is documented in detail in the Central Public Health & Environmental Engineering Organization (CPHEEO) manual on Water Treatment and Supply, chapter 15.

Laboratory-Based Rural Monitoring

Currently, MPWs are responsible for monitoring all 300,000 rural drinking water sources in Maharashtra. MPWs are responsible for collecting samples from all of the rural drinking water sources in their jurisdiction four times a year to test for bacteriological contamination. The area and number of sources that each MPW is responsible for varies. Once collected, the MPWs transport the samples to either one of the 35 district public health laboratories or one of the 375 rural hospital laboratories depending on proximity. Samples at the district public health laboratories are tested using the multiple tube method while samples at the rural hospital laboratories are tested by H_2S P-A.

The drinking water quality data is stored at the district public health laboratories or rural hospital laboratories where it is tested, and is reported sent weekly to the Primary

Health Center. If there is evidence of contamination, the results are communicated to the Primary Health Center the same day and the gram panchayat treats the source by chlorinating. After disinfection, another sample is taken and tested for residual chlorine. If this sample does not show residual chlorine, a third sample from the source is sent by the MPW to the district public health laboratories for bacteriological testing.

The data from the rural hospital laboratories is also sent each month to the district public health laboratories, which compiles all of the information, and sends it to the Directorate of Public Health at the state level. The Directorate of Public Health shares this report with the other state level organizations, the WSSD and the DPR.

Scenarios Not Characterized

In Maharashtra there is an effort underway to transition from the current "rural operational monitoring" scenario to a new approach to monitoring rural water supplies that involves four components. The first component of this new approach would involve five-person community based volunteer teams (one for each gram panchayat) testing each rural water supply four times per year using an H_2S P-A field kit. The second component would involve these five-person teams delivering water samples four times or less per year to the nearest district public health laboratory or rural hospital laboratory for multiple tube testing. The third component would involve the district public health laboratories conducing duplicate testing on 10% of samples brought to the rural hospital laboratories. The fourth component would involve the district public health laboratories testing each rural water supply one time per year using the multiple tube method. This essentially encompasses dual operational monitoring, inter-laboratory comparison, and surveillance.

4.4.3 Cost Analysis for Maharashtra

The cost of monitoring associated with each scenario in Maharashtra is presented in **Table 6**. Testing costs represent the cost of materials associated with the test method for each scenario. Labor costs represent the cost of the time sampling staff and laboratory staff spend on microbiological monitoring. Sampling cost represents the cost associated with transportation to sampling sites and back to the laboratory where samples are tested.

Table 6: Costs for Maharashtra monitoring scenarios

	Rural	**Small urban**	**Large Urban**
Target population	55,777,647	19,493,831	18,368,426
Actual practice			
# tests per year	1,200,000	34,662	25,308
testing cost	$1,944,000	$56,152	$40,999
labor cost	$1,800,000	$45,061	$32,900
sampling cost	$3,208,920	$92,690	$67,676
total cost	$6,952,920	$193,903	$141,575
Prescribed practice			
# tests per year	1,200,000	34,662	25,308
testing cost	$1,944,000	$56,152	$40,999
labor cost	$1,800,000	$45,061	$32,900
sampling cost	$3,208,920	$92,690	$67,676
total cost	$6,952,920	$193,903	$141,575

4.4.4 Maharashtra Discussion

In Maharashtra, monitoring in rural, small urban, and large urban settings meets or exceeds targets. Expenditures in rural monitoring are very high, as the target frequency is four times per year. There are effectively only three scenarios occurring in Maharashtra for monitoring of microbiological parameters; one for each setting. There is currently no surveillance monitoring, although for rural settings they are in the process of switching to an approach that would include surveillance monitoring as well as inter-laboratory comparisons. Interview accounts of monitoring for large urban settings did not consistently indicate that monitoring was occurring as it was supposed to, but online databases showed complete water quality data for these settings for the preceding year.

4.5 Jordan

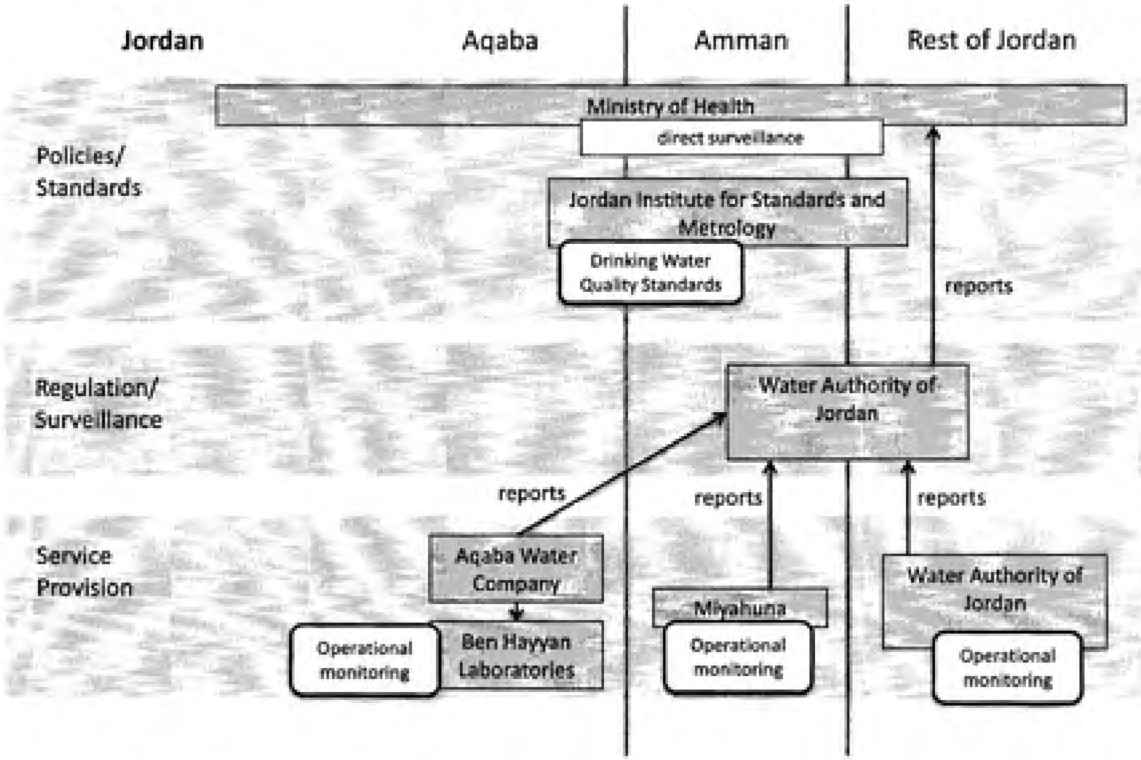

Figure 10: Water sector map for Jordan as it relates to drinking water quality monitoring

4.5.1 Key Organizations:

The **Aqaba Water Company** (AWC) is a private company responsible for water supply within the Aqaba governorate in the south of Jordan. They are responsible for operational monitoring of water supply there, which they subcontract to the Ben Hayyan laboratory as they do not have the capacity themselves.

Ben Hayyan (BH) laboratories is a quasi independent non-governmental organization that among other capacities can test water quality. They were funded initially by an EU grant combined with national funding for materials and supplies. They do operational monitoring on subcontract for AWC.

The **Jordan Institution for Standards and Metrology** (JISM) is the standards board for all of Jordan, and their activities in the water sector extend beyond standards. In addition to setting water quality standards and monitoring standards, they set procedures. They also organize and chair the Permanent Technical Committee, which meets every 5 years to create and amend any water policy, regulation, or standards. The most relevant document published by the JISM is JS286:2008, the national standard for drinking water quality, which includes sampling procedures and testing procedures.

The **Ministry of Health** (MoH) is responsible for participating in formation of water quality standards, monitoring standards and regulation, as well as responsible for surveillance monitoring of all water supply in Jordan.

Miyahuna is the private water supplier for all of Amman, the capital city of Jordan. Miyahuna is actually ~85% owned by WAJ, but operates as a private company. They are responsible for 80% of the total samples that JISM 286.2001 specifies as operational monitoring.

The **Royal Scientific Society** (RSS) is an independent organization that among other capacities has the laboratory facilities and experience to test water for microbiological and biological parameters. They operate on subcontracts from various groups especially in emergency situations such water-related disease outbreaks. They also have had a contract that has been running for over 20 years in which they monitor various environmental sites for biological water quality.

The **Water Authority of Jordan** (WAJ) is the central actor in the water sector in Jordan. They are a participating organization in the formation of regulations and standards. They act as supplier for all of Jordan excepting Amman (Miyahuna) and Aqaba (AWC). They are responsible for monitoring all drinking water in Jordan excepting the Aqaba governorate. In Amman they are responsible for 20% of the total yearly samples taken from the distribution system. They also act as regulator for water supply in Jordan, receiving water quality reports from AWC, Miyahuna, and the Ministry of Health.

4.5.2 Drinking water quality monitoring scenarios in Jordan

Miyahuna Operational Monitoring: Amman

Miyahuna is a quasi-autonomous non-governmental organization that supplies piped drinking water to the city of Amman. They pump water from many sources both surface and groundwater to a centralized treatment plant where they operate a central laboratory, from there they pump water into the Amman distribution system. All testing is done at the centralized laboratory; using the multiple tubes method to test for total coliforms and *E.coli* for treated and distributed water, and thermotolerant coliforms for raw water. This laboratory has a dedicated sampling team that does all sampling; for raw water, treated water, pumping stations, reservoirs, and the distribution system. The frequency of testing for distribution system samples is determined based on national water quality standards (JS:286 2008), while all samples not taken from the distribution system are based on an internal framework updated yearly. Results are used internally for adjusting operating procedures and for quality control, and are also reported monthly to the Water Authority of Jordan, which acts as a regulator.

Aqaba Operational Monitoring: Aqaba Governorate

The Aqaba Water Company (AWC) supplies drinking water to the entire Aqaba governorate (WAJ is not involved as Aqaba is governed in a unique manner as a special economic zone). The AWC contracts Ben Hayyan laboratories (a quasi-autonomous non-governmental organization) to perform all monitoring activities for their water supplies, including sampling, testing, and reporting. The frequency of sampling and testing used by Ben Hayyan is determined from the Jordan national standard (JS 286:2008). Results are used primarily for operational purposes, but are additionally reported from AWC to WAJ on a monthly basis.

Water Authority of Jordan Operational Monitoring

The Water Authority of Jordan acts as both a water supplier and a water sector regulator. They provide drinking water to the entire country including rural areas, but excluding Amman and the Aqaba governorate, which are supplied by Miyahuna and the Aqaba Water

Company (see above scenarios). WAJ operates a central water quality laboratory in Amman that is ISO accredited, where they conduct all regular testing (they also have two mobile-laboratories that are used for emergencies, outbreaks, and development of new sources). WAJ is responsible for operational monitoring of all drinking water they supply directly, as well as for 20% of operational monitoring in Amman (Miyahuna is responsible for 80% of monitoring in Amman). Drinking water samples are tested for total coliform and thermotolerant coliform using the multiple tube method, and for *E.coli* if there is a positive result for total coliform or thermotolerant coliform. WAJ bases sampling and testing frequency on the Jordan national standard (JS:286 2008). This primary purpose of this scenario is identification and response to contamination events, though information is reported monthly to the Ministry of Health as well.

Ministry of Health Surveillance Monitoring

The Ministry of Health monitors all drinking water in Jordan (including the Aqaba governorate). The Ministry of Health operates 19 laboratories that are equipped to test for total and thermotolerant coliform using the multiple tube method. The Ministry of Health sampling and testing frequency is based on the Jordan national standards (JS:286 2008), as the "control party," which involves testing fewer samples per month than the "operating party."

Scenarios Not Characterized

In Jordan there was one additional monitoring scenario that was not characterized, as it is not a regular scenario. The Royal Scientific Society (RSS) periodically tests drinking water for microbiological parameters both for research purposes and to check the quality of water being supplied by Miyahuna and WAJ. Historically the RSS has also been involved in water quality monitoring during and following water-related disease outbreaks.

4.5.3 Cost Analysis for Jordan

The cost of monitoring associated with each scenario in Jordan is presented in **Table 7**. Testing costs represent the cost of materials associated with the test method for each scenario. Labor costs represent the cost of the time sampling staff and laboratory staff spend on microbiological monitoring. Sampling cost represents the cost associated with transportation to sampling sites and back to the laboratory where samples are tested.

Table 7: Costs for Jordan monitoring scenarios

	Miyahuna	**Aqaba**	**WAJ**	**Ministry of Health**
Target population	2,800,000	107,000	6,407,000	6,407,000
Estimated practice				
# tests per year	6,052	540	25,000	16,944
testing cost	$9,804	874.8	$40,500	$27,449
labor cost	$19,536	$1,743	$80,697	$54,693
sampling cost	$20,440	$1,824	$84,433	$57,225
total cost	$49,780	$4,442	$205,630	$139,368
Prescribed practice				
# tests per year	6,390	540	14,518	16,944
testing cost	$10,352	$875	$23,519	$27,449
labor cost	$20,626	$1,743	$46,863	$54,693
sampling cost	$21,581	$1,824	$49,032	$57,225
total cost	$52,559	$4,442	$119,414	$139,368

4.5.3 Jordan Discussion

Drinking water quality monitoring is split into operational monitoring and "control party" monitoring, or surveillance monitoring. Operational monitoring is currently split among the public Water Authority of Jordan, and two semi-private suppliers, namely the Aqaba Water Company and Miyahuna. There is currently an effort underway in Jordan to privatize the remaining water supplies that serve large, densely populated urban centers, with the hope that drinking water treatment, distribution, and monitoring will become more efficient as a result. Current monitoring practice in Jordan matches the government mandated approach very closely, with all scenarios reaching or exceeding the required number of samples and tests per year (in **Table 8** it appears that Miyahuna is below the required number of samples, which is an artifact of practice in 2008 being compared to 2010 guidelines which involves an increased required number of samples). Every water supply in Jordan is monitored in at least two scenarios (with the capital city of Amman being monitored in triplicate). This results in large expenditures per capita.

4.6 Normalized Costs for India and Jordan

Table 8 and **Figure 11** display the normalized costs of each monitoring scenario in each state in India. The solid bars in **Figure 11** represent how much is actually spent in practice per 1000 capita based on the estimated number of water samples collected and tested on a yearly basis. Hollow bars represent what it would theoretically cost per 1000 capita if the target number of water samples were collected and tested on a yearly basis.

Table 8: Normalized scenario costs per 1000 capita for India and Jordan, estimated practice and prescribed practice

Country	State	Method	Scenario		
			Rural	Small Urban	Large Urban
India	Uttar Pradesh	Estimated	$3.74	$0.00	$0.36
		Prescribed	$28.14	$12.36	$6.74
	West Bengal	Estimated	$10.42	$1.05	$4.10
		Prescribed	$94.37	$21.26	$6.52
	Maharashtra	Estimated	$124.65	$9.95	$7.71
		Prescribed	$124.65	$9.95	$7.71

Country	Method	Scenario			
		AWC	Miyahuna	WAJ	Ministry of Health
Jordan	Estimated	$18.77	$41.51	$18.64	$21.75
	Prescribed	$17.78	$41.51	$32.09	$21.75

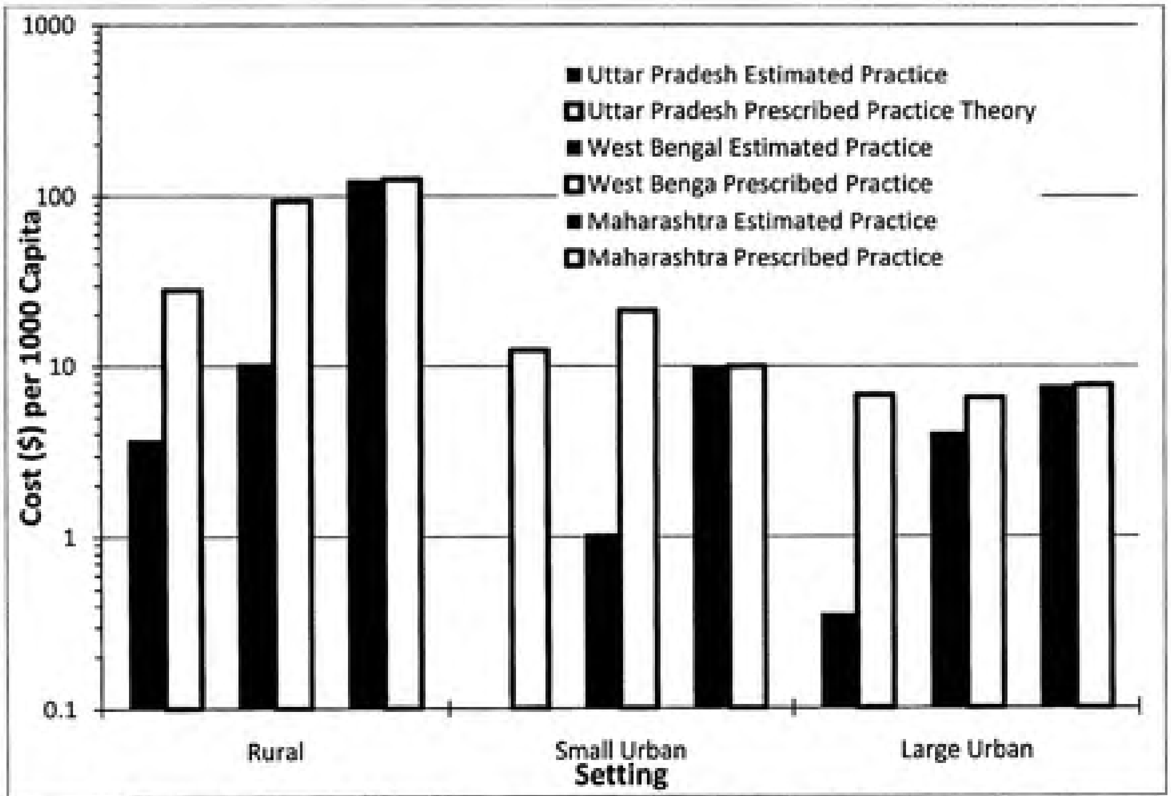

Figure 11: Normalized costs for monitoring in three states in India, estimated practice and prescribed practice.
Note: costs are compared across settings.

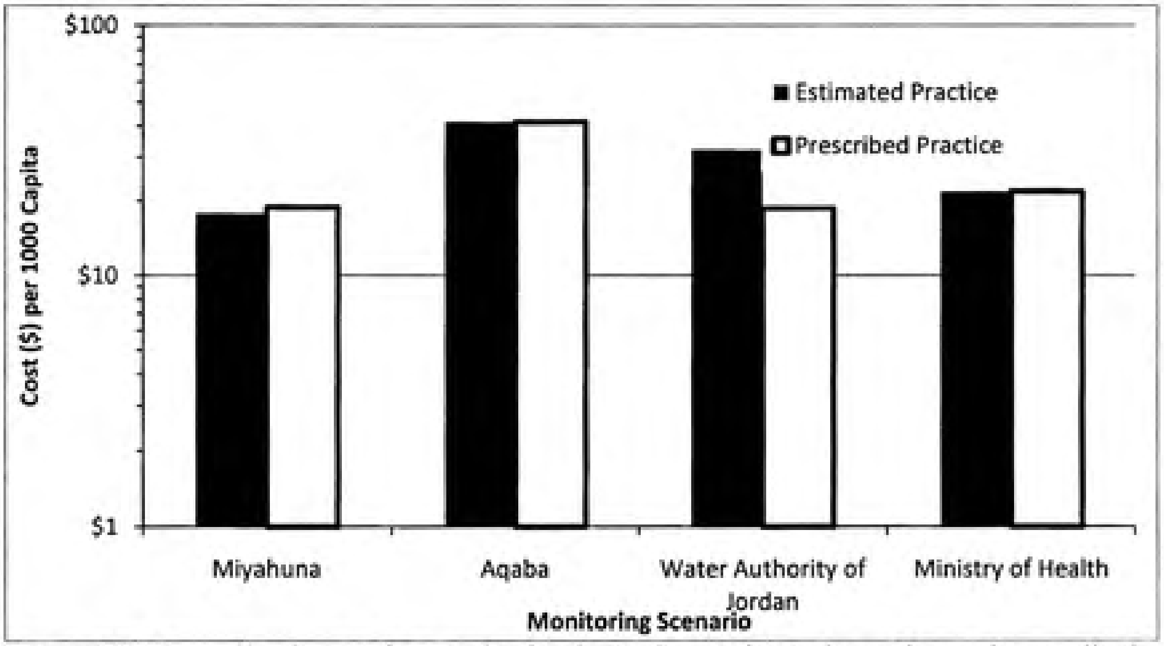

Figure 12: Normalized costs for monitoring in Jordan, estimated practice and prescribed practice
Note: Costs are compared across organizations

4.6.1 India Inter-State Comparison

Drinking water quality monitoring both as prescribed (as set out in national and state guidelines) and as practiced varies significantly between states. This could result from responsibility for oversight and implementation of monitoring falling to the state or sub-state level in India rather than to the national government. Practices vary from having a distinct monitoring scenario for each setting (rural, small urban, and large urban) to having multiple scenarios for each setting, although in practice typically only one monitoring scenario is actually practiced for each setting (see *Scenarios not characterized* at the end of each India State section). There exist two specific models for rural monitoring (both described in national guidelines developed by the DDWS); volunteer community-based teams using H_2S P-A field kits, and laboratory-based testing using local government for sampling and public health laboratories for multiple tube testing. In Uttar Pradesh, rural operational monitoring is supposed to occur in the field, though the majority of rural monitoring is done using H_2S P-A kits incubated in the 58 district laboratories; in West Bengal, 114 laboratories are used for rural monitoring; and in Maharashtra, 410 laboratories are used for rural monitoring. This variation in capacity between states is paralleled for small urban and large urban monitoring, although the differences are not as extreme.

For two out of three states characterized, small cities and towns are not monitored comprehensively or frequently. In Uttar Pradesh and West Bengal, the monitoring approach for rural point-sources and for the largest cities is specified, but small urban settings are not included. They have distribution systems used by large populations which justifies more frequent monitoring than the twice per year rural schedule, but they do not have the resources to operate their own laboratories so they cannot monitor in the manner that the largest cities do. In Maharashtra this discrepancy is addressed by equipping the 375 rural hospitals with the capability to conduct multiple tube testing for total and thermotolerant coliform. This represents a large capital cost (which is not reflected in cost analysis), but allows for high frequency testing of small urban water supplies. In all three states characterized, the largest cities are equipped with their own water quality laboratory, and conduct frequent testing of treated water and the distribution system.

In India, water supply is often covered by multiple scenarios in theory, but only one scenario is actually practiced thus each water supply is not tested by multiple agencies except in a few select cases. However, reporting mechanisms are clearly defined for each scenario, and generally include reporting summarized data to various agencies and departments within the state government, as well as entering raw data into state and national online databases.

This audit approach saves money, but can only be functional if reporting is actually occurring. Online databases at the state and national level in India indicate that not all test results are reported between agencies.

As can be seen in **Table 8** and **Figure 11** at the end of the Results section, there is a difference between actual expenditures and theoretical expenditures in Uttar Pradesh and West Bengal. Additionally, across all three settings there is a consistent pattern, with the least expenditures per capita occurring in Uttar Pradesh, expenditures in West Bengal being slightly higher, and expenditures per capita in Maharashtra being the highest, where estimated and prescribed practice are closely aligned.

Monitoring as currently practiced in India is not comprehensive in that the not all drinking water supply is being tested for microbiological parameters. Monitoring of piped supplies in large urban and small urban settings involves sampling from treatment plants and distribution systems, but peri-urban populations who do not have piped supply are not receiving monitored drinking water. Monitoring in rural areas focuses on boreholes, but populations who collect water from an unimproved rural drinking water source do not receive monitored drinking water. Additionally, in two of three states characterized in India, resource limitations result in monitoring scenarios not being conducted as they are prescribed to occur, thus testing is at a lower frequency than desired or not all water supply is being tested. Rahman et al. (2010) found similar situations in the nine countries included in their research; in urban settings water suppliers do the majority of monitoring and thus focus on piped supply, and in rural settings operational monitoring rarely occurs and there is often inadequate capacity for comprehensive surveillance monitoring.

As can be seen from institutional maps presented in the Methods section, drinking water quality monitoring is a complex issue, with many factors affecting the approach to monitoring as well as how monitoring is actually practiced. It is then conclusively say what is causing the differences between estimated and prescribed practice in each state characterized. Characteristics of each state worth noting are GDP and percent of the population living in rural areas. These are shown below in **Table 9**.

Table 9: Indicators correlated with water quality monitoring expenditures for three states in India.

	GDP per capita (USD)	Percent rural
Uttar Pradesh	$323	79%
West Bengal	$618	72%
Maharashtra	$905	57%

An increase in GDP is associated with an increase in expenditures per capita, as is an increase in water access. An increase in percentage of population in a rural setting is associated with a decrease in expenditures per capita. Gross Domestic Product relates to the available financial capita within a state, and thus could be affecting how much is spent. Rural populations in the three states included in this study range from one water source per 85 people to one water source per 185 people. Rural populations thus pose an obstacle in conducting comprehensive and frequent monitoring, as they require more tests per capita on a yearly basis than do urban populations. Additionally, collecting samples involves greater transportation costs as rural water supplies are spread out across large areas.

The theoretical cost per 1000 capitais similar between states, the small variation exists because the distribution of population varies. In Uttar Pradesh, theoretical monitoring costs for rural settings is significantly lower than in Uttar Pradesh, because monitoring is supposed to be conducted on a volunteer basis by community-based teams, so there are no sampling costs, and labor costs are lower and accrue to community members rather than to the government or to utilities. Test material cost is also lower as an H_2S P-A field kit is used which is cheaper than the multiple tubes method used in other scenarios.

4.6.2 Inter-Country Comparison

The total cost of monitoring per 1000 capita of for the three states in India is $24.89, calculated by adding all scenario costs together and dividing by the combined population of all three states. In Jordan, the total cost of monitoring per 1000 capita is $62.31, calculated in the same manner. This reveals that in USD more is being invested in monitoring in Jordan than in India when normalized using population. It is important to note that USD doesn't represent the value of currency in each country. Included in **Table 3** (see **Section 4**) is the purchasing power parity as international dollars for India (2.72) and Jordan (1.74), which represents the buying power of $1 in each country. Even after accounting for the differential buying power of USD in each country, Jordan is investing significantly more money in monitoring than India on a per capita basis.

The cost per capita for India and Jordan underestimates the actual costs of monitoring, as it only includes certain marginal costs (test materials, laboratory and sampling labor, transportation), but excludes other marginal costs (laboratory maintenance, management labor) and all capital costs which may be significant. Cost estimates presented here show that the majority of monitoring cost is not from test materials. If the additional marginal costs and capital costs mentioned above were included in cost estimates, the contribution of test materials to the overall cost of monitoring would be reduced even further.

5.0 Conclusions

In practice, each country and state has a small set of monitoring scenarios being implemented. There are many scenarios that have been described in India and Jordan that are not occurring regularly, as focus is on first implementing monitoring for basic operational purposes. If existing scenarios were cheaper to implement, scenarios not currently conducted such as additional testing during the rainy season, surveillance monitoring, and inter-laboratory comparisons could be implemented as well.

In all but one scenario in Uttar Pradesh, the majority of the cost of monitoring comes from labor and transportation, and not from test materials. These are also the components of monitoring that are most amenable to cost reductions. Comprehensive monitoring of all drinking water supply would be possible in low resource settings if labor and transportation costs associated with monitoring were removed or reduced. The community-based rural monitoring scenario in Uttar Pradesh illustrates this, as volunteer teams test their own water sources, removing labor and transportation costs.

This research focused on institutional mapping of the water sector in study countries, as well as a detailed cost analysis for two countries. However, drinking water quality monitoring is designed to impact water quality and public health. An evaluation of the effectiveness of water quality monitoring at informing decision making and water quality management is the logical next step. A quantitative comparison of effectiveness of different monitoring scenarios combined with this analysis of costs would enable a cost-effectiveness evaluation of monitoring scenarios and an optimization of practice.

Lessons learned

A thorough search of the literature revealed limited existing evidence and experience on studying water quality monitoring programs, thus this research involved use of novel methods. If this study were to be repeated, additional data and detail would yield more comprehensive and refined results and analysis. Additional data that would aid this study include:

- Unit costs for labor and test materials collected while in the field. This information would refine the cost analysis by removing the assumptions around unit costs. Results would then show whether or not there are economies of scale, or other factors that affect the costs of monitoring (besides the number of tests).
- How water quality managers, laboratory staff, and samplers spend their time. This would refine the cost analysis by removing assumptions about the amount of time required to collect and process samples. Additionally, including water quality managers in data collection would broaden the cost analysis to include management of water quality information, rather than just sampling and testing.
- How laboratories are maintained and restocked. This would allow the cost analysis to be broadened to include laboratory costs beyond just direct testing. This is currently a limitation to this study; Uttar Pradesh has 58 laboratories while Maharashtra has 410 laboratories but this information does not change the cost analysis.

Data collected during this study that would be better in more detail includes:

- More estimates on the number of tests processed for each monitoring scenario. These could come from lab technicians, samplers, or water quality managers. More estimates would allow for triangulation, and higher confidence (or even a confidence interval) on the calculated number of tests per year for each scenario.

- Size and capacity of laboratories. This would contribute to the addition of laboratory maintenance to the cost analysis.

As prescribed practice and actual practice vary significantly (especially in lower resource settings), the above information is not available strictly from gray literature or from interviews at the top of organizations involved in water quality monitoring. This data must be collected from lower level employees such as samplers and laboratory technicians, who tend to be more distributed and harder to reach during field work. Simultaneous field work in all study countries made it difficult to adjust data collection as the study progressed. The above information would be easy to collect if field work was conducted sequentially, with experiences in each study country influencing the methods in the following country.

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Appendix A: Rahman et al. 2011. "Coordination for Clean Water: A Comparison of Institutional Frameworks for Managing Drinking Water Quality"

Coordination for Clean Water: A Comparison of Institutional Frameworks for Managing Drinking Water Quality

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ABSTRACT

At the institutional level, the WHO recommends a set of complementary monitoring activities for effectively managing drinking water quality and delivering safe water supplies; however, in practice, there exist a variety of institutional approaches to managing drinking water quality. We characterized institutional frameworks for drinking water provision and management in nine countries, focusing on roles and responsibilities and existing capacity for water quality monitoring. Responsibility for water quality testing of formal piped urban supplies is typically well defined, with attention placed on both 'operational,' and 'surveillance' (compliance) monitoring. In rural and informal urban settings, however, legal requirements for operational testing are generally vague. In addition, operational monitoring in these settings is difficult to implement due to limited capacity and informal management systems. Consequently, in rural and informal urban areas, risk management approaches should be emphasized. Public health authorities commonly carry out surveillance of all drinking water supply types. Our analysis suggests that direct surveillance of rural and informal urban water sources should be strengthened to support progressive safety improvements. To leverage existing resources for surveillance of rural and informal urban water sources, we suggest that surveillance agencies could increase 'audit-based' surveillance of piped urban water providers, while maintaining oversight of these water suppliers' quality control activities.

Key words: water quality, institutional arrangements, operational monitoring, surveillance, water quality testing

INTRODUCTION

Health and economic consequences of unsafe water

The burden of water borne diseases on public health and economic development is well known: diarrheal diseases are the second leading contributor to the global disease burden (measured by DALYs), and the majority of this disease burden falls on the least developed countries due to inadequate water and sanitation infrastructure and services (WHO 2008a). Furthermore, Hutton et al. estimate that the global economic benefits of meeting the Millennium Development Goal for water, including health care savings, time gained from reduced illness and convenience time gained, would total US $23 billion (2007). The magnitude of the health and economic impacts that might be realized by reducing the prevalence of diarrheal disease accounts for the emphasis placed on improving access to safe water and improved sanitation facilities in the United Nations' Millennium Development Goals and other international and national development programs (WHO 2008b).

Defining the institutional landscape

The provision of safe drinking water is a multi-sectoral issue linked to environmental public health, engineering, and both rural and urban development. Achieving access to safe drinking water requires input and action at national and sub-national levels and across numerous stakeholders, including administrative and policy agencies, public health officials, and urban and rural water providers (WHO 2004).

As a result, effective water quality management requires:

- sector coordination with the clear assignment of responsibilities for water quality monitoring among different actors
- development of appropriate regulations, including provisions for water quality monitoring and encouraging compliance including enforcement

- measures to ensure adequate financing for water testing programs
- water quality data management and associated communication
- appropriate public health and water management responses to water quality data (developed from WHO 2004).

In order to identify effective national strategies for progressively improving water safety and increasing access to safe water, this study compares institutional frameworks for water quality management and broadly characterizes the nature of testing activities in a range of developing country settings. We highlight commonalities and differences in water quality governance and evaluate consistency with WHO guidelines, which state that national water quality regulations should be applicable to all water supplies and that "this would normally embody different approaches to situations where formal responsibility for drinking-water is assigned to a defined entity and situations where community management prevails" (WHO 2004, 31). Given the vast differences in water supply governance between rural, peri-urban, and urban areas, this recognition that water quality management approaches must be tailored to the management context is critical, and in this paper we explore a range of governance models.

Water Quality Monitoring Best Practices

We have analyzed institutional frameworks for water quality management in the context of the two main water quality testing activities: 'operational monitoring' and 'surveillance monitoring'. According to the WHO *Guidelines for drinking-water quality, 3rd edition* (GDWQ) monitoring of drinking water quality through the complementary activities of operational monitoring (or water quality control) by the water supplier and surveillance by an independent agency is fundamental to the delivery of safe drinking water to consumers (2004).

Regular operational testing by suppliers is considered a key tool for maintaining process control and verifying water quality. Optimal operational testing triggers immediate corrective actions when test results indicate that a water supply system is compromised. The GDWQ recommend that responsibility for operational monitoring be assigned to water suppliers in national legislation (WHO 2004). In addition, operational monitoring should be carried out frequently, at the local level and can be limited to a set of critical control parameters such as pH, residual chlorine, turbidity and observable factors related to the integrity of the system (Howard 2002; WHO 2004). Finally the frequency of operational monitoring and the number of samples tested should be calculated based on population served and the nature of the control point concerned.

Surveillance monitoring, also referred to as compliance monitoring, requires an independent agency to assess the compliance of all drinking water supplies, including unimproved and untreated sources, with national standards (WHO 2004). Unlike operational monitoring, surveillance monitoring can be infrequent but should include a comprehensive evaluation of the adequacy of supplies, including quality, quantity, accessibility, affordability and continuity (Bartram 1999, Howard 2002). Sanitary inspections, which consist of on-site evaluations of the safety and integrity of water supplies, often form one component of water supply surveillance (Bartram 1999, WHO 2004). This study focused on water quality testing, and did not include an assessment of responsibilities for sanitary inspections. Drinking water surveillance is ideally linked to resource allocation, planning for improvement of water supply systems, and oversight of suppliers.

As noted in the GDWQ and confirmed by this research, there are two general strategies for water quality surveillance: a direct assessment and an audit-based approach. When implementing direct assessments, the surveillance agency independently collects and analyzes water quality samples (WHO 2004). In contrast, in an audit-based system, the surveillance agency reviews records, including water quality monitoring results, submitted by the supplier (WHO 2004). Surveillance agencies that employ an audit-based approach must maintain independent oversight in order to verify the reliability of data (Howard 2002). For example, the surveillance agency should review and approve the suppliers' water quality control plans, make regular site visits to review records and ensure that the suppliers are carrying out operational monitoring and implementing safeguards in the production and distribution of water (WHO 2004).

Urban *versus* rural settings

In this paper, we contrast rural water supplies with urban water supplies, recognizing that water supply types and management systems vary widely within rural and urban areas. Formal, regulated suppliers (public or private) operating large piped systems with household and public connections serve many urban areas (WHO & UNICEF 2008; AGUASAN 2008). However, the urban poor, many of whom live in informal settlements or peri-urban areas, often do not have access to this formal water supply infrastructure. Consequently, the urban poor commonly rely on informal supplies such as water vendors, household wells, public taps, and small private systems with varying degrees of official recognition and regulation (Aguilar & López 2009).

According to the 2008 Joint Monitoring Program (JMP) report, overall access to improved drinking water sources remains low in rural areas compared to urban areas (WHO & UNICEF 2008). Rural areas are commonly served by a mix of small municipal systems, community-managed supplies, and household sources; which include boreholes, wells, protected springs, hand pumps and small piped systems (WHO 2004; AGUASAN 2008). These supply types and associated management systems are also often found in small towns, and peri-urban settlements (AGUASAN 2008).

METHODS

Our analysis compares institutional frameworks for drinking water quality management in: Bolivia, Brazil, Cambodia, Ecuador, Lao PDR, Malawi, Peru, Sri Lanka, and Viet Nam. The countries analyzed range from low income to upper middle income, based on World Bank income level categorizations for 2008 and span the major developing country regions including South America, Southeast Asia, South Asia and sub-Saharan Africa (World Bank 2010). We do not assess all possible water management frameworks here; rather, for a diverse set of countries, we explore and document existing institutional frameworks for water quality management. We identify frameworks that appear to promote water quality management for the full range of water supply scenarios, rather than attempting to quantify the relative effectiveness of these frameworks, as measured by quantity of testing or the provision of safe water. In addition, our analysis focuses on institutional frameworks for water quality monitoring as a key component of water quality management; although, we recognize other activities such as source protection, water treatment, safe distribution and operation and maintenance are critical for the delivery of safe water supplies.

We first developed institutional framework 'maps', depicting institutional roles at three levels: 1) drinking water policy development; 2) surveillance and regulatory compliance assessment; and 3) service provision and operational monitoring (Figure 1 a-i). We have used dashed lines to identify surveillance and operational testing activities that are mandated by standards or policies but do not appear to be carried out in practice. We then analyzed the institutional maps, summarizing their content in a tabular format, and discuss patterns that emerge in the division of responsibilities, gaps in coverage, and factors that influence the actual scope of monitoring activities. Recognizing the potential influence of level of economic development, we evaluate observed outcomes in light of the relative income levels of the countries analyzed.

Our maps are based on published reports, 'gray literature', policy documents and interviews with relevant water sector actors carried out by the Aquaya Institute and the University of North Carolina (UNC) as an activity of the Aquatest Research and Development Program, an initiative to design water quality management tools that are optimized for resource-poor settings (Rahman 2010).

Specifically, this study combines information gathered by Aquaya to support the implementation of field pilots of the Aquatest system in a range of countries and by UNC in an effort to characterize water quality monitoring practices in low-income countries. Key stakeholders and officials interviewed for this research include representatives of national and regional offices of ministries of health, water ministries, private water utilities, water sector regulators, academic institutions and multi-laterals such as UNICEF, UN HABITAT, and the Water and Sanitation Program of the World Bank.

A key function of standards and policies is to clarify roles and responsibility for both surveillance and for operational monitoring. As such, water quality standards and policy documents from the selected countries were critical for developing these institutional maps. The standards and policies reviewed for this research are listed in Table 1.

In summary, these institutional maps depict our understanding of water quality monitoring activities based on information gathered through reviewing published reports and policy documents, site visits and consultation with key stakeholders. The institutional maps distill the major groups involved in drinking water provision and water quality management, however, they do not attempt illustrate in full detail institutions and activities at every administrative level. As such, they may not reflect all the complexities nor subtleties of activity on the ground.

Table 1: Water Quality Standards and Policies Reviewed

Country	Document Title	Published By	Date
Bolivia	NB512/512R: National Regulations for the Control of Water Quality for Human Consumption	Ministry of Services and Public Works, Vice-ministry of Basic Services	2004/ 2005
Ecuador	INEN 1108.Ecuadorian Technical Standard: Drinking Water: Requirements	Ecuadorian Institute for Standardization (INEN)	---
	Code of Practice on Drinking Water Quality	Ministry of Health	2008
Peru	Regulation of the official physical, chemical and bacteriological requirements that drinking water should comply with to be considered potable.	Supreme Resolution.	1946
	Drinking Water Quality Regulation (not officially signed into law)	Directorate of Environmental Health (DIGESA), Ministry of Health	2006
Brazil	Ordinance No. 518	Ministry of Health	2004
Vietnam	National Technical Regulations on Drinking and Domestic Water Quality	Ministry of Health	2009
Lao PDR	Decision on the Management of Quality Standards for Drinking Water and Household Water Supply	Ministry of Health	2005
Cambodia	Drinking Water Quality Standards	Ministry of Industry, Mines and Energy	2004
	Draft Water Supply Policy	Ministry of Industry, Mines and Energy	*Current draft*
Sri Lanka	SLS614: Specification for Potable Water: Part 1: Physical and Chemical Requirements	Sri Lanka Standards Institution	1983
	SLS614: Specification for Potable Water: Part 2: Bacteriological Requirements	Sri Lanka Standards Institution	1983
	National Policy on Water Supply and Sanitation	National Water Supply and Drainage Board	2002
Malawi	National Water Policy	Ministry of Irrigation and Water Development	2005

RESULTS

Figure 1 (a-i) provides schematic outlines of the institutional frameworks for water service provision and water quality management in both the rural and urban water sectors for each country studied. Table 2 presents a summary of the characteristics of each country's institutional framework for water quality monitoring alongside income level classifications.

Table 2: Summary of Institutional Frameworks by Income Level

Country	World Bank Income Level Classification	Institutional Framework Included in Standards or Policies	Presence of a Surveillance Agency	Operational monitoring mandated for formal suppliers	Operational Monitoring mandated for informal suppliers	Presence of a Regulatory Agency	Institutional Arrangement meets WHO Guidelines*
Cambodia	Low Income	No	No	Yes	Vague	No	No
Lao PDR	Low Income	Vague	Yes	Yes	Yes[B]	Yes	Yes
Malawi	Low Income	Vague	No	Yes	Vague	No	No
Bolivia	Lower Middle Income	Yes	Yes	Yes	Yes[B]	Status Unclear	Yes
Ecuador	Lower Middle Income	Yes	Yes	Yes	No	No	Yes
Sri Lanka	Lower Middle Income	No	Yes	Yes	Vague	No	No
Vietnam	Lower Middle Income	Yes	Yes	Yes	Yes[B]	No	Yes
Brazil	Upper Middle Income	Yes	Yes	Yes	Yes	No	Yes
Peru	Upper Middle Income	Yes[C]	Yes	Yes	No	Yes	Yes

*In this analysis, a country's institutional arrangements were categorized as meeting WHO recommendations if i) there is an agency responsible for independent surveillance, ii) water service providers are responsible for operational monitoring, and iii) standards or relevant policies present an institutional framework (even if vague) for water quality management. The WHO GDWQ state that community operators or households should conduct sanitary surveys and that operational monitoring is only advised where sources are treated (WHO 2004). Therefore, a mandate for operational monitoring for informal or community supply managers is not considered critical for meeting WHO recommendations here. This table only evaluates whether the institutional frameworks meet WHO recommendations and not the capacity to implement testing programs.

[B] Although standards suggest that even informal supply managers should carry out operational testing, in practice this capacity does not exist and local actors do not appear to expect operational monitoring of community managed or informal supplies.

[C] In 2006 Draft Regulation, not yet promulgated as official law.

Operational Monitoring: actors and their responsibilities

The institutional maps and the summary in Table 2 illustrate that across the nine countries reviewed formal water suppliers, usually serving urban areas, are the primary institutions that conduct operational monitoring in practice. However, the definition of *water supplier* is central to understanding legal responsibility for operational testing. Standards in Vietnam, Lao PDR, Bolivia and Brazil suggest that, in addition to formal suppliers, informal, semi-professional managers and individuals are also responsible for carrying out operational testing (Ministry of Services and Public Works, Bolivia 2005; Ministry of Health, Lao PDR 2005; Ministry of Health, Vietnam 2009). In contrast, Peru's 2006 draft standards and Ecuador's 2005 *Code of Practice for Drinking Water Quality* limit the requirement for operational monitoring to formal suppliers and do not appear to include local water committees that primarily manage rural supplies in both countries. Such committees typically comprise volunteer members of the community rather than trained professionals, and their distinction in law reflects this contrast to trained and remunerated professional managers. Standards and policies reviewed for Cambodia, Sri Lanka and Malawi do not provide detailed definitions of suppliers nor do they clarify the scope of the requirement for operational testing. Despite these apparent differences in legal mandates, observations from site visits to study countries suggests that only well-resourced formal water suppliers currently carry out operational testing.

During site visits we observed that formal water suppliers in major urban centers in the developing world such as those of Quito, Lima, Vientiane, and Phnom Penh commonly have high quality laboratory infrastructure and technically trained staff to conduct frequent operational monitoring, including bacteriological analysis. Across the countries surveyed, site visits and consultation with experts indicates that the majority of state and provincial utilities in smaller population centers also have at least basic internal laboratories and trained staff for monitoring. For instance, provincial public utilities in Cambodia, Laos, Peru and Vietnam,

In contrast, small public or private suppliers and community managers rarely have laboratory facilities and few use field tools for basic monitoring. For example, many of the small utilities serving intermediate and small towns in Ecuador, Peru and Bolivia do not have access to laboratory facilities and do not conduct on-site testing. Similarly, nine out of sixteen small public water suppliers in Cambodia have on-site laboratories, while the remaining public utilities and the numerous private sector suppliers (~270) lack laboratories and testing equipment. In Sri Lanka, the National Water Supply and Drainage Board (NWSDB) regularly monitors its own supplies but community water groups, local authorities and private sector water providers do not appear to carry out operational testing. Operational monitoring of informal supplies in peri-urban and urban areas in all countries reviewed also appears rare.

The GDWQ and many national water quality guidelines suggest that operational monitoring should be carried out for only a limited set of critical control parameters that can indicate failures in source protection, treatment and distribution systems (WHO 2004; Ministry of Health, Vietnam 2009; Directorate of Environmental Health, Peru 2006; Ministry of Health, Lao PDR 2005). Interviews and site visits confirmed that in the countries reviewed many suppliers do limit frequent operational testing to these critical control parameters, which commonly include pH, turbidity, and free chlorine, all of which can be measured using simple, affordable field tests. Large utilities with high quality laboratory facilities do test for a wider range of parameters (for example Nitrates, Fluoride, Arsenic, Manganese), although less often than for critical control parameters.

Surveillance monitoring: actors and their responsibilities

The institutional maps illustrate that in the majority of countries analyzed, responsibility for water quality surveillance lies with health authorities. Regional public health departments in Bolivia, Brazil, Ecuador, Lao PDR, Peru, and Vietnam serve as independent, external auditors of the quality of water service provision, and water quality standards and policies in these countries clearly allocate responsibility for surveillance to the health sector.

As highlighted in Table 2, Malawi, and Cambodia lack independent surveillance agencies Nevertheless, in both Malawi and Cambodia, the institutions responsible for water service provision do carry out oversight monitoring of the supplies under their jurisdiction. In Malawi, drinking water is provided through a combination of para-statal Water Boards, which serve Malawi's major cities and regional market centers, and rural water schemes that are managed by district assemblies. The Ministry of Irrigation and Water Development (MoIWD), which is responsible for overall water sector policy and ensuring service provision, tests rural supplies directly and audits operational monitoring reports submitted by the Water Boards. Testing is conducted by MoIWD's dedicated Water Quality and Pollution Control Department at regional laboratories.

In Cambodia, the Ministry of Mines, Industry and Energy (MIME), which is responsible for regulating piped service provision, also plays an oversight monitoring role. MIME independently collects and analyzes water samples from public and licensed private piped supplies. In the case of public suppliers, this surveillance activity complements operational monitoring carried out on-site. Private suppliers, in contrast, do not carry out operational testing. While MIME's testing ensures some oversight of piped supplies (although not fully independent), it does not reach beyond piped systems. As a result, the majority of rural water supplies in Cambodia are rarely tested after installation.

Sri Lanka presents a hybrid form of surveillance. Sri Lanka's Ministry of Health and Nutrition is the country's regulatory body for water quality, however, it does not have sufficient laboratory infrastructure to conduct comprehensive surveillance monitoring. As a result, the Ministry of Health and Nutrition has an agreement with the National Water Supply and Drainage Board (NWSDB) that allows Public Health Inspectors to collect samples from community managed supplies and deliver then to NWSDB laboratories for analysis. The Ministry of Health and Nutrition then audits results from all tests carried out at NWSDB's laboratories, including results from both NWSDB and community managed supplies.

Regulatory Bodies

In addition to water service providers and surveillance agencies, our research identifies independent, third party regulators as a third authority involved in water quality management in a minority of countries. These regulators, such as the National Superintendant of Sanitation Services (SUNASS) in Peru and the Water Supply Regulatory Committee (WSRC) in Lao PDR oversee the provision of services by formal water suppliers, ensuring that they meet water quality standards, tariff regulations and other requirements. Both SUNASS and WSRC only regulate urban service providers. In both countries, these regulatory agencies are also charged with strengthening utilities and ensuring their financial viability.

SUNASS plays a central role in water quality management for piped urban supplies in Peru. Every three months, water service providers are required to submit water quality reports to SUNASS, which subsequently alerts the Ministry of Health when water quality data indicates health risk. In addition, SUNASS spot checks the quality of service through annual testing for a limited number of water quality parameters. Peru's water quality regulations state that, together, operational testing by suppliers and audit by SUNASS constitute 'water quality control' or operational monitoring (DIGESA 2006). Although SUNASS' activities do not eliminate the need for independent surveillance by DIGESA, they do ensure frequent assessment of the quality of service provision. SUNASS currently only regulates suppliers in large urban centers, but will soon expand its jurisdiction to include utilities in smaller urban centers (Salazar 2010).

In Lao PDR, the Water Supply Regulatory Committee (WSRC) has a similar independent regulatory function. The WSRC sets performance obligations, undertakes tariff reviews, provides assistance to provincial authorities in issuing licenses to suppliers, and otherwise provides guidance and oversight of the sector (Water Supply Regulatory Committee, 2009). However, the WSRC views water quality reports infrequently and, it appears, primarily in order to produce an annual sector report. Both SUNASS in Peru and WSRC in Lao PDR explicitly do not have jurisdiction over rural water supplies.

Current water sector policies in Cambodia and Sri Lanka state the intention of establishing water sector regulatory agencies; however, to date such bodies have not been formed in either country (MIME, Water Supply Policy: Draft; NWSDB, Sri Lanka 2002). Cambodia's draft Water Supply Policy, which has not yet been promulgated as official law, states that the key functions of such a body would include regulating private sector participation in the water sector, and increasing credibility, quality of service and public confidence in the water supply (MIME, Water Supply Policy: Draft).

DISCUSSION

This analysis of institutional frameworks indicates that in practice, operational monitoring is limited to formal piped supplies; whereas, water quality testing of community managed rural supplies and other semi-professional or informal systems is infrequent, even in well regulated, relatively wealthy contexts. In practice, water quality testing of these supplies is primarily conducted through surveillance programs.

Although the legal requirement for formal suppliers to conduct operational monitoring is clear in all countries reviewed, site visits and discussions with water sector experts reveal that there is a wide range of existing capacity and activity. While water suppliers in major urban centers usually are well equipped for carrying out water quality testing, smaller suppliers consistently lack capacity for even basic water quality testing, even in wealthier countries such as Peru. While not observed within the study countries, our experience in other countries indicates that some suppliers, both large and small, also subcontract to private or NGO laboratories for testing when they do not have on-site capacity. In Brazil, the National Health Foundation, or FUNASA, provides support for operational monitoring to small municipal suppliers. In addition, municipal governments are required to support quality control for community or household supplies that lack formal management. In this research we did not observe other examples of such external support for operational monitoring and hypothesize that Brazil's capacity for this level of support to small supply managers is linked to both its clarity of institutional roles and its improving economic status.

As noted in the results, water suppliers commonly limit operational testing to a set of critical control parameters. In addition to pH, turbidity and free chlorine, which are commonly tested on-site, standards in Bolivia, Cambodia, Lao PDR, Peru and Vietnam include thermotolerant coliforms or *E. coli* in the set of priority parameters. Similarly, Ecuador's *Code of Practice for Drinking Water Quality*, quotes the WHO GDWQ in stating that "The severity of the possible consequences of microbial presence is such that its control and supervision should always be a priority and must never be compromised" (Ministry of Health, Ecuador. Article 1.4). However, among all but the largest water providers, the microbial quality of water supplies is evaluated infrequently and only when samples are sent to external laboratories or during periodic surveillance monitoring by the health authorities. There are a variety of potential explanations for why microbiological monitoring is minimal even when it is recognized as important; these include lack of sufficient trained staff, financial resources, or appropriate technology.

Although institutional responsibility for water quality surveillance lies with the health sector in most countries and is generally linked with a broader public health framework, there are cases where responsibility for surveillance monitoring has not been established. The absence of a surveillance agency in Cambodia and Malawi may be due to either a lack of resources or to political constraints. Both countries fall into the World Bank's low income classification and their water quality standards and policies do not clearly establish institutional responsibilities for water quality management. In contrast, Lao PDR, which is also a low income country that lacks explicit description of institutional responsibilities in its standards, does have a surveillance agency, albeit with limited resources, in place.

In both Malawi and Cambodia, oversight monitoring by the ministries responsible for water supply appears to be one strategy for promoting the safety of water supplies in the absence of an independent surveillance agency. However, oversight monitoring by the institutional responsible for water delivery is not an optimal substitute for independent surveillance, as there is an inherent conflict of interest in the department responsible for service provision regulating water quality. Independent surveillance is not only an important mechanism for gathering unbiased data but is also critical for developing national strategies for ensuring the safety of all water supplies, particularly remote, non-piped sources.

Even where institutional responsibility for surveillance is well established, surveillance agencies are commonly constrained by limited funding and human resources. For instance, Vietnam's provincial health departments have trained staff and laboratory equipment for water quality testing but lack sufficient funding for regular sample collection and analysis. As a result, some provincial health departments appear to only carry out testing when water service providers or the provincial Center for Rural Water Supply and Environmental Sanitation (P-CERWASS) offices send in samples and pay a fee for the analysis. As a result, surveillance is sporadic, especially in rural areas. In this analysis we note that low and lower middle income countries such as Bolivia, Ecuador, Lao PDR and Sri Lanka, and upper middle income countries such as Peru and Brazil, all experience challenges in reaching isolated rural areas with water quality surveillance programs.

A potential institutional strategy for addressing constraints to rural monitoring may be an increasing reliance on audit surveillance of urban supplies that allows public health agencies to concentrate resources on direct surveillance of rural and informal urban supplies. Increasing reliance on audit surveillance requires strong operational monitoring by formal suppliers, and can potentially be facilitated by urban regulatory bodies that maintain political and financial independence from the central government. Such regulators can play a role in water quality monitoring where suppliers have a clearly defined legal responsibility to meet water quality standards (Howard 2002). SUNASS in Peru, for example, is responsible for collecting and reporting operational monitoring data to the Ministry of Health, which, in turn, enforces any necessary sanctions. SUNASS' active engagement with audit surveillance complements the Ministry of Health's infrequent direct surveillance of urban piped systems in Peru

The WHO guidelines for surveillance and control of community supplies appear to support such tailored strategies, suggesting, "In countries where urban water suppliers have established effective quality control, the surveillance agency may choose to place greater emphasis on the problems of less well served populations" (WHO, 1997, 13). However, in the countries studied in no cases had local authorities or experts identified this strategy as means for addressing constraints to water quality surveillance.

Although our current data is insufficient to demonstrate whether the presence of urban regulatory bodies in Peru and Lao PDR or the use of audit surveillance by the Ministry of Health in Ecuador have resulted in more effective surveillance monitoring programs, we propose that there is a need for policy advocacy in this area and for further research on the impact of these strategies. As noted in our institutional maps and analysis, urban regulators are present or emerging in other developing countries.

In this research we noted that in several countries, health authorities have dual responsibility for water quality surveillance and for providing support to community water supply managers in rural areas. For example, in Lao PDR the Center for Environmental Health and Water Supply (Nam Saat) is responsible for ensuring access to safe water in rural areas and for surveillance of all drinking water supplies. Similarly, the regional health departments in Ecuador and Peru actively support community water groups that manage rural supplies. Often in rural areas, water quality testing for surveillance purposes is the only source of water quality information and, although infrequent, can directly motivate improved water management. Where rural surveillance is weak, source testing at installation may be the only opportunity for evaluating the quality of rural supplies. Further research is required to understand whether these surveillance agencies provide similar support to managers of informal supplies in urban and peri-urban areas. Although this dual support and surveillance role of health authorities suggests potential for bias, in reality strict regulation of community managed supplies is challenging, and perhaps inappropriate, for a number of reasons. First, when a community manages their own supplies, responsibility for management is not institutionally distinct from the users themselves (Howard 2002). In this context, experts argue that surveillance agencies should play a role in supporting improvement, rather than citing violations (Howard 2002). Secondly, given the known high rates of non-compliance of small community managed water supplies, it is unclear what benefit strict third party surveillance for the purpose of evaluating compliance would provide (Howard 2002).

In addition to strengthening capacity for operational and surveillance monitoring, it appears there is also a need for clear assignment of responsibility for water safety management in water quality standards or complementary policy documents. Such clarity can promote institutional accountability and reduce redundancy of roles.

Further research is required to evaluate the impact of the water quality monitoring programs carried out in these countries. Such research will allow further analysis of the relative effectiveness of these institutional frameworks. We also recognize that in addition to institutional frameworks, factors such as political will, budget allocation to the sector, technical capacity and overall level of development all impact the effectiveness of water quality monitoring programs.

CONCLUSION

A key feature that emerges from our analysis is the relative clarity of institutional roles for water quality monitoring of formal urban water supplies, with responsibility for operational monitoring assigned to water providers. Among these suppliers however, capacity for operational testing varies greatly. While only the largest water suppliers maintain fully equipped chemical and microbiological laboratories, formal suppliers in many secondary towns attempt to maintain some equipment and staff for monitoring critical control variables. In contrast, small public and private suppliers in even relatively wealthy countries lack even this basic capacity, an area that requires strengthening.

We observe that responsibilities for operational testing of rural and informal urban water supplies, which range from household wells to community supplies and private piped water systems, are often poorly defined, largely due to the lack of professional management. Water supply managers in these settings, whether community water associations, private operators or individual households, tend to lack technical capacity and resources to support water quality testing. Given the nature of these management systems, it may be necessary to strengthen monitoring techniques that emphasize risk management such as sanitary inspections as a prelude to full operational testing.

Independent surveillance, usually by public health agencies, comprises at least two distinct methods: in rural areas, direct assessment of water supplies is the norm, and in urban settings, formal suppliers with comprehensive testing programs often supply the surveillance authority with water quality data from their facilities as part of an audit-based surveillance approach. We hypothesize that relying on formal suppliers to submit water quality data can allow surveillance agencies to concentrate resources on direct surveillance of rural and informal urban supplies. This dual approach to surveillance monitoring appears prudent in optimizing the use of available resources and should be more actively promoted.

Increasing audit-based surveillance of formal urban suppliers, however, also poses significant challenges. First, audit-based surveillance requires high quality operational monitoring by suppliers and, as noted above, many formal suppliers will require assistance in developing this capacity. Policies that clearly specify operational monitoring requirements can support improvements in practice. Independent regulators can also take on responsibility for enforcing operational monitoring requirements and in collecting audit surveillance data. In addition, in order to maintain the independence and reliability of surveillance, it is critical that the surveillance agencies employing the audit-based approach establish independent audit activities such as laboratory inspections and review of water safety management activities.

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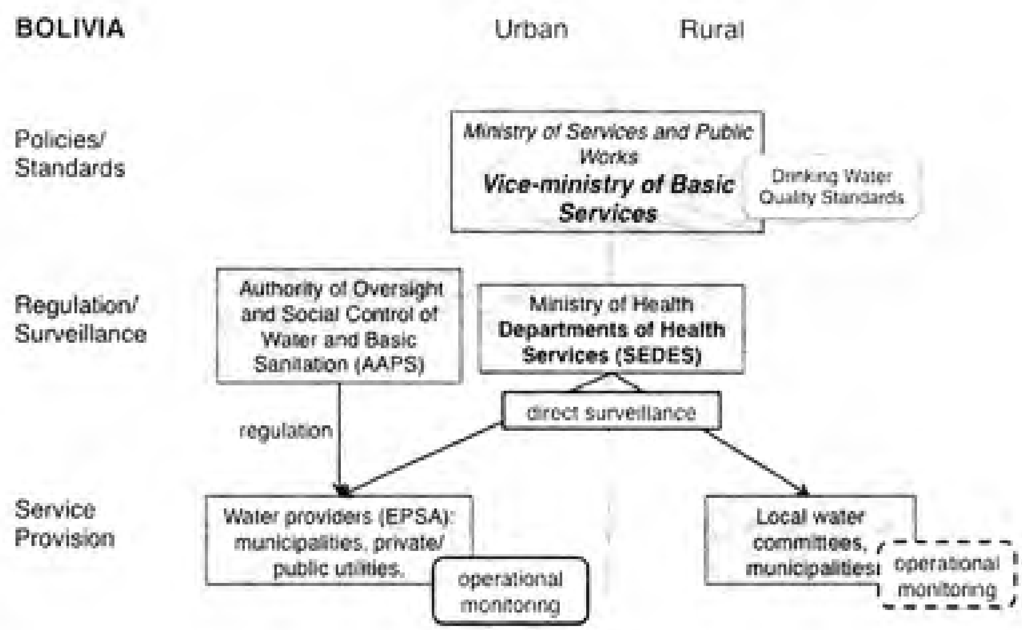
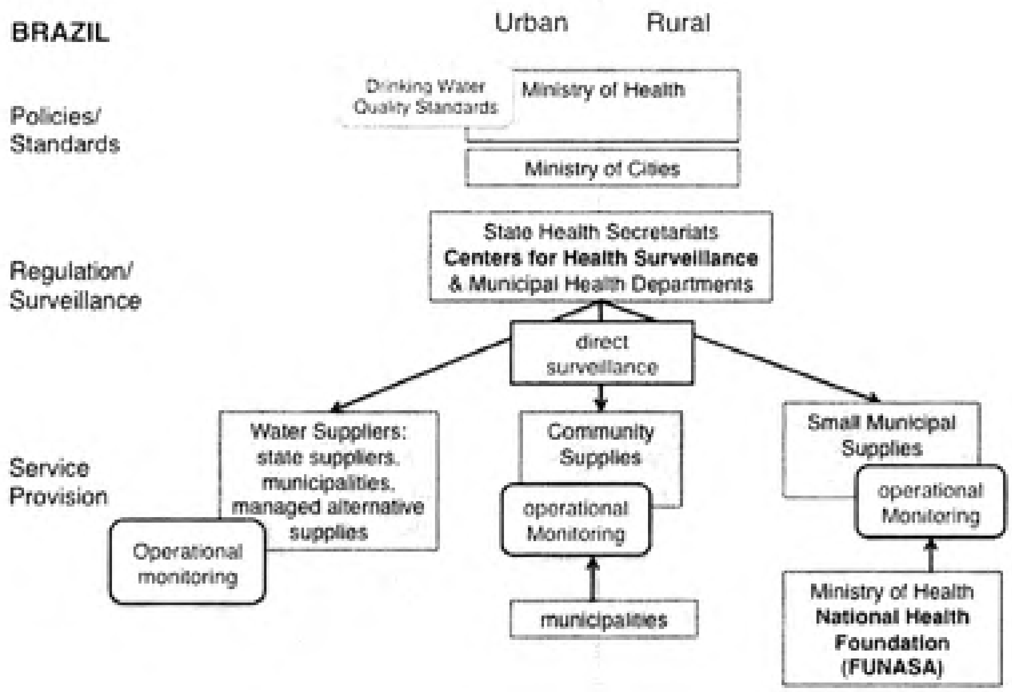
Figure 1(a-i)

Figure 1: Institutional Arrangement Maps for Drinking Water Provision and Quality Management

Each country's institutional map displays the primary institutions involved in drinking water delivery and water quality testing for both urban and rural areas. The ministries responsible for overall sector policies and strategies, and for developing water quality standards, are illustrated in the top row. The institutions responsible for water quality surveillance and regulation of water quality compliance are listed in the central row. The institutions responsible for service provision are specified in the third row. The maps also identify the institutions responsible for operational and surveillance testing activities. Arrows indicate relationships between institutions and dashed lines indicate where an activity is mandated in standards but not carried out in practice. The maps include the primary institutions involved, but do not attempt to list in detail all entities involved at each administrative level.

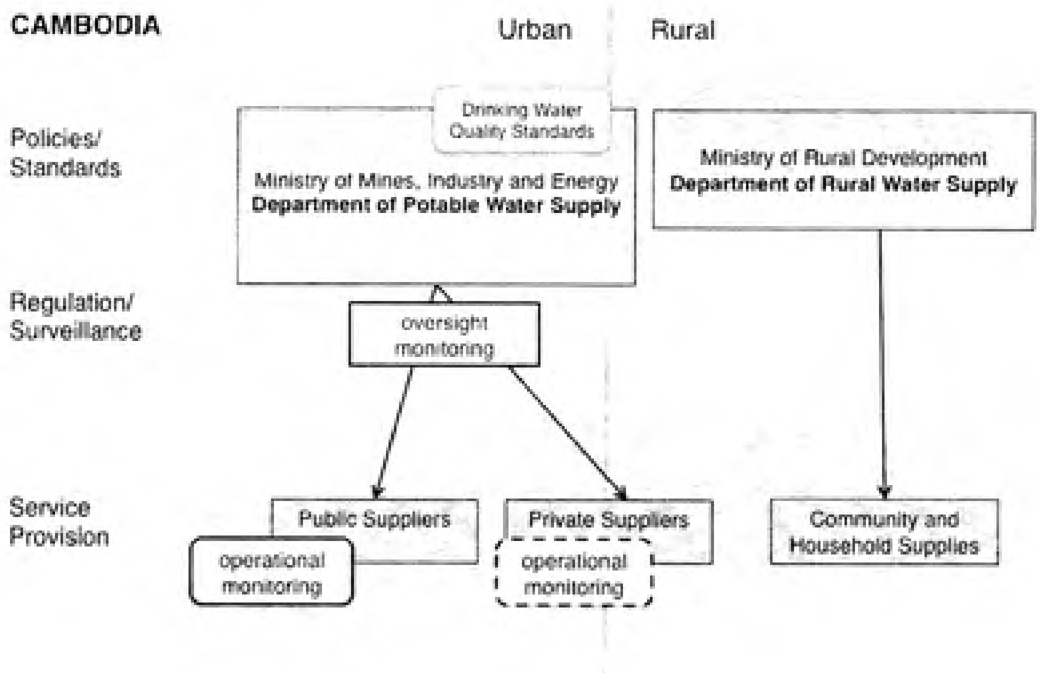


a) Bolivia. Despite legislation stating that all water service providers should carry operational testing in Bolivia, testing is limited to well resource urban Water Service Providers in practice. Until recently, the Superintendent of Basic Sanitation (SISAB) was responsible for regulating water and sanitation service provision in Bolivia. However, SISAB was replaced in 2009 by official decree by the independent Authority of Oversight and Social Control of Water and Basic Sanitation (AAPS), which now oversees the water sector. Further research is required to understand the motivation for and impact of this recent change. Throughout the country, Departments of Health Services or SEDES are responsible for water quality surveillance.

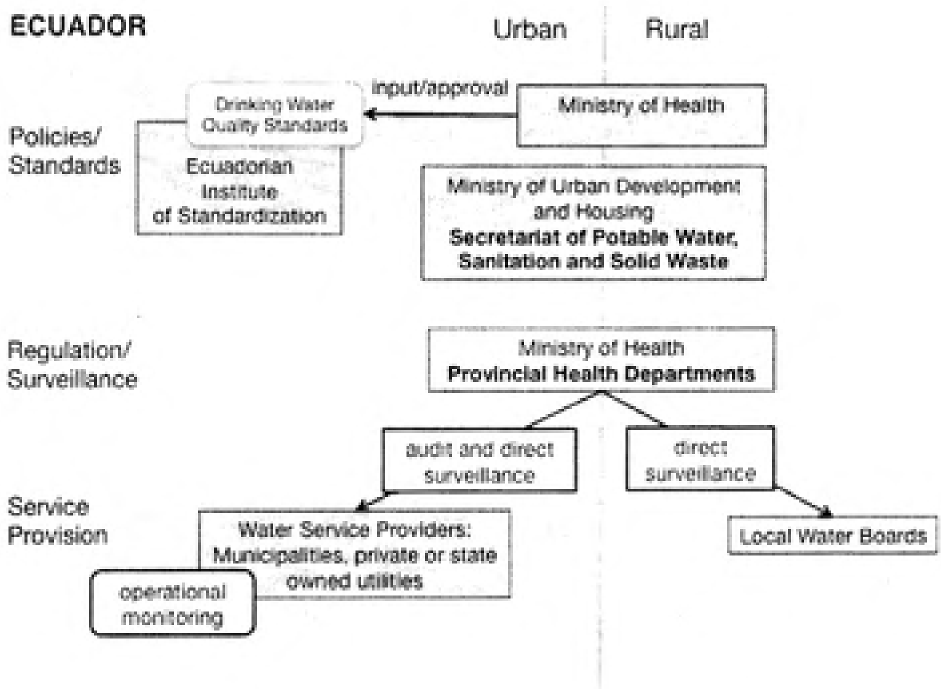


b) Brazil. Water suppliers in Brazil are mandated through national regulations to carry out operational testing. Most formal suppliers are able to comply with this requirement. The National Health Foundation or FUNASA, a department within the Ministry of Health, provides support for operational monitoring to small municipalities that lack sufficient internal capacity. Alternative supplies, without formal management, such as household wells and community supplies, also receive support from municipalities to carry out operational testing. Water quality surveillance in Brazil is carried out by health authorities through the Centers for Health Surveillance of the State Health Secretariats and municipal health departments. These health authorities carry out direct surveillance of both the larger piped networks and alternative supplies through a national program called VIGIAGUA.

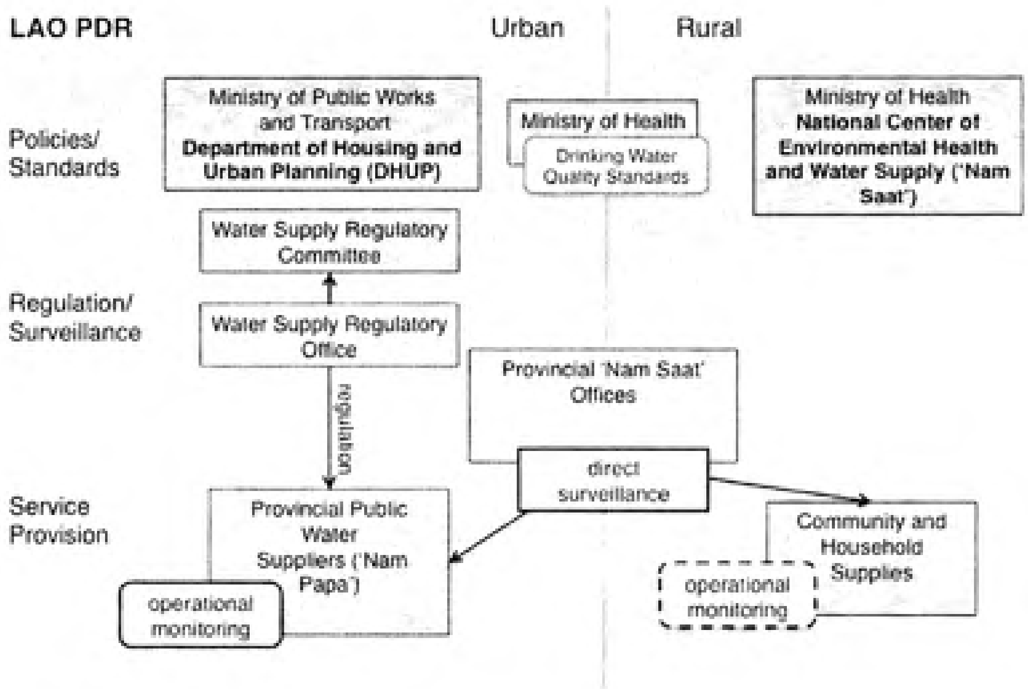
CAMBODIA



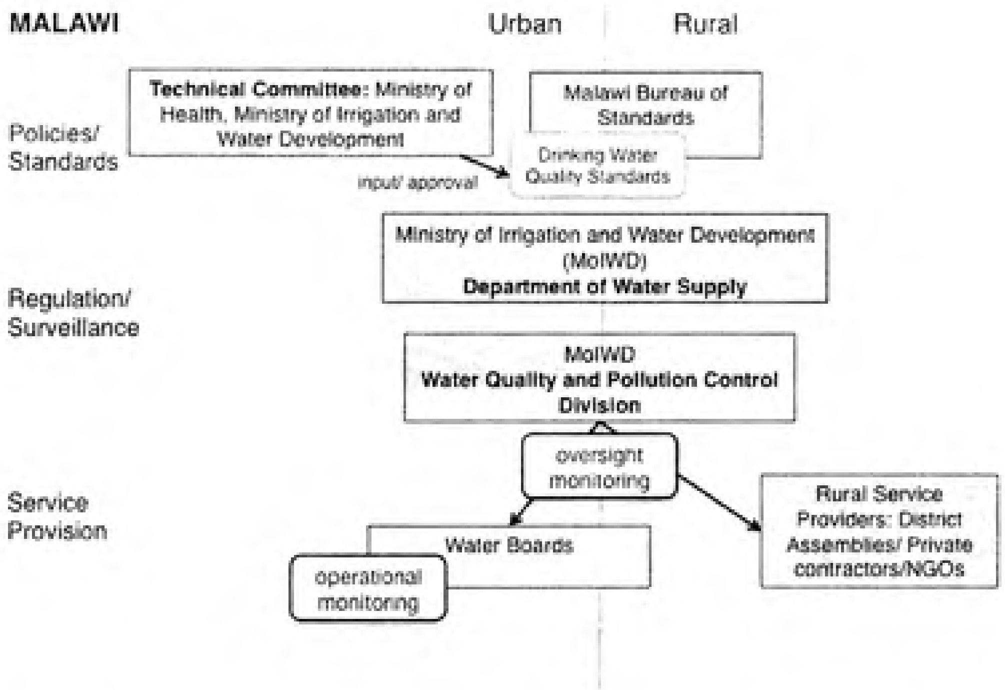
c) Cambodia. Cambodia's Department of Potable Water Supply of the Ministry of Mines, Industry and Energy (MIME) develops policies and plans for urban water supply, supervises public suppliers and conducts oversight monitoring of both public and private piped water suppliers. Private suppliers serve both rural and urban population centers. Few of Cambodia's public water suppliers have laboratory equipment and capacity for carrying out on-site operational testing for the full range of operational parameters. As a result, a number of public suppliers only test for residual chlorine and in some cases send samples for analysis to the suppliers that do have capacity for microbiological testing. The majority of private suppliers do not appear to carry out any operational testing. Private supplies are currently only monitored through MIME's oversight monitoring program. Whether the requirement for operational testing, as stated in MIME's Drinking Water Quality Standard, applies to both public and private suppliers is unclear. The Department of Rural Water Supply of the Ministry of Rural Development (MRD), which supports rural source development, generally requires testing of rural water sources at installation; however, there is no regular operational monitoring of these supplies nor independent surveillance.



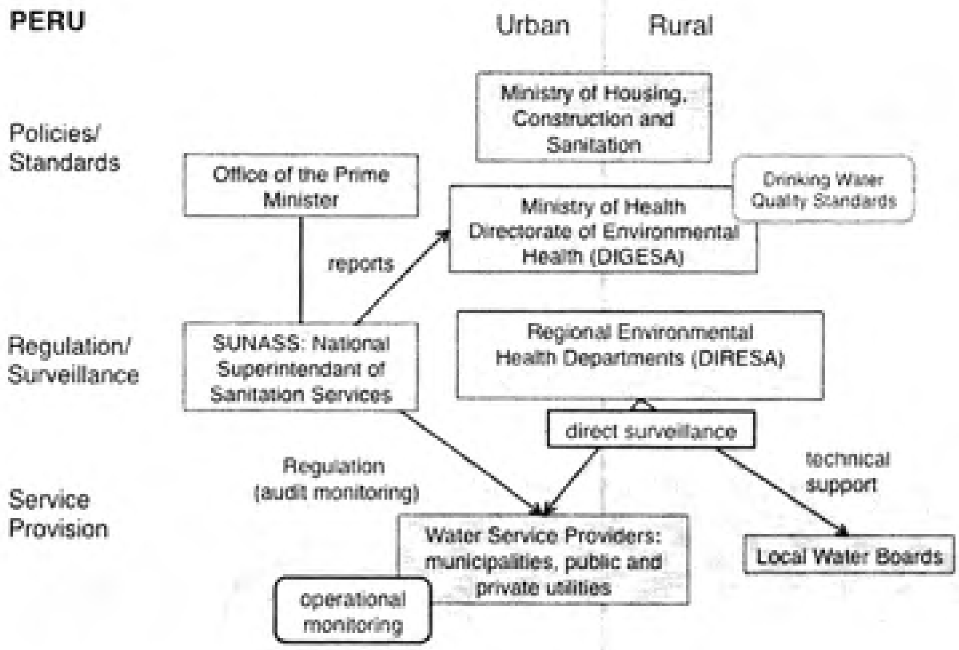
d) Ecuador. Municipalities are the primary service providers in urban areas and local water boards primarily manage rural supplies in Ecuador. These municipal providers vary in their capacity for on-site operational testing and local water boards lack resources for on-site testing. The Ministry of Health, through their Provincial Health Departments and local staff carry out regular direct surveillance of both urban and rural water supplies and also provide technical support to local water boards. Where water service providers have strong capacity for operational monitoring, the Provincial Health Departments generally employ an audit-based approach for surveillance monitoring.



e) Lao PDR. Responsibility for urban and rural water supply is divided between two ministries in Lao PDR. The Department of Housing and Urban Planning of the Ministry of Public Works and Transport is responsible for urban service provision, whereas the National Center for Environmental Health and Water Supply (Nam Saat) of the Ministry of Health supports rural infrastructure development and maintenance for rural supplies. The Water Supply Regulatory Committee (WSRC), established in 2005, regulates the urban water sector through its secretariat, the Water Supply Regulatory Office (WASRO). In addition Nam Saat, through their provincial offices, carries out surveillance of both urban and rural supplies. Lao PDR's water quality regulations suggest that operational monitoring should be carried out for all supplies, including community and household supplies; however, in practice it is limited to urban, piped supplies (Lao PDR. Ministry of Health 2005).

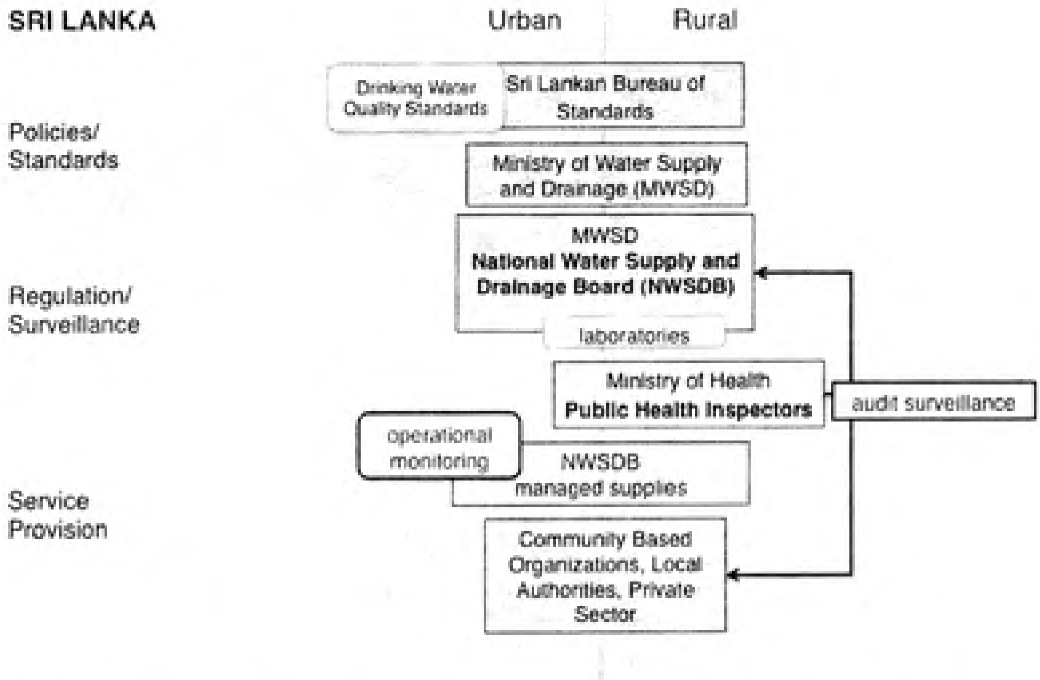


f) Malawi. The Department of Water Supply of the Ministry of Irrigation and Water Development is the primary ministry responsible for water service provision, water sector policy and regulation in Malawi. Five parastatal government Water Boards under the jurisdiction of the MoIWD provide water services in Malawi's major cities of Lilongwe and Blantyre and in several towns and market centers. As a result of decentralization of water sector responsibilities, District Assemblies are responsible for managing rural supplies, although these are often developed by multiple actors including private contractors, and NGOs in addition to local government itself. Water Boards generally have laboratories for carrying out operational monitoring in their service areas. The Water Quality and Pollution Control Division of the Ministry of Irrigation and Water Development (MoIWD) carries out water quality testing of all supplies and has laboratory facilities in each of Malawi's three administrative regions. MoIWD carries out direct operational monitoring of rural supplies and audit's the water quality testing records of the Water Boards. Malawi lacks an independent surveillance agency.



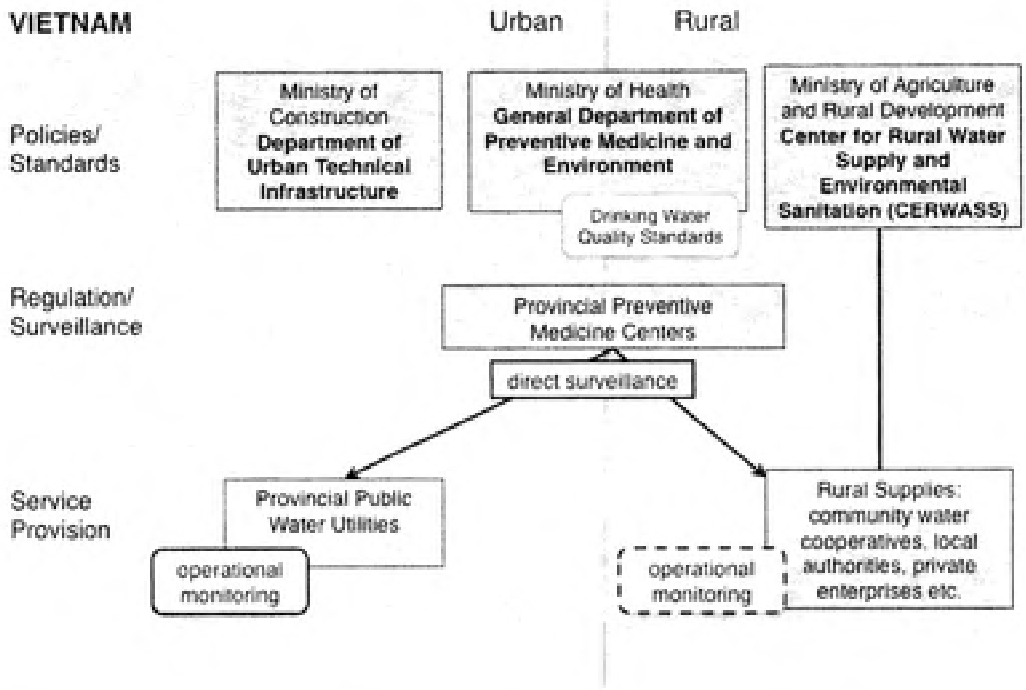
g) Peru. While Peru's largest utilities have laboratory facilities and technical staff for carrying out operational testing, smaller municipal suppliers often do not. Water Suppliers in Peru are regulated by the National Superintendant of Sanitation Services (SUNASS), an autonomous regulatory body under the Office of the Prime Minister established to ensure that service providers meet performance standards (Personal Insight, *Drinking Water Safety International*, 2010). Regional departments of the Directorate of Environmental Health (DIGESA) of the Ministry of Health not only carry out surveillance but also provide technical support to the local water boards that manage rural supplies. It is difficult to determine whether the requirement for operational testing in Peru's new draft standards applies to these local water boards; however, they generally lack capacity to test their supplies.

SRI LANKA



h) Sri Lanka. The Ministry of Water Supply and Drainage and its implementing arm, the National Water Supply and Drainage Board (NWSDB) are the primary actors in both urban and rural water service delivery in Sri Lanka. However, NWSDB is increasingly promoting private sector participation in urban areas and is encouraging local authorities, Community Based Organizations (CBOs), and entrepreneurs to take over the management of rural supplies (National Water Supply and Drainage Board, Sri Lanka 2002).

Although the Ministry of Health is responsible for water quality surveillance in Sri Lanka, the Ministry does not have sufficient laboratory facilities to fully support such testing, whereas NWSDB has good laboratory infrastructure. As a result, NWSDB not only carries out operational testing of their own supplies, but also analyzes samples submitted by public health inspectors from alternative supplies. Data from NWSDB's testing is submitted to the MOH to satisfy audit based surveillance requirements.



i) Vietnam. Vietnam's provincial public utilities, the primary service providers in urban areas, generally have capacity to carry out on-site basic operational testing. Outside of major cities, many providers do not test for bacteriological parameters on-site. Rural water supply managers do not appear to have any capacity for operational testing. The Ministry of Health, through the Provincial Preventative Medicine Centers (PMCs), is responsible for water quality surveillance but does not have sufficient funding to support a comprehensive surveillance program. As a result the PMCs rely on fees from water utilities and other government agencies to support their testing program.

Appendix B: List of countries included in cluster analysis

Albania
Algeria
Angola
Argentina
Armenia
Aruba
Austria
Azerbaijan
Bangladesh
Belarus
Benin
Bolivia
Botswana
Brazil
Burkina Faso
Burundi
Cambodia
Cameroon
Canada
Chad
Chile
China
Colombia
Comoros
Congo
Costa Rica
Cote d'Ivoire
Croatia
Cuba
Cyprus
Czech Republic
Democratic Republic of the Congo
Denmark
Djibouti
Dominican Republic
Ecuador
Egypt
El Salvador
Estonia
Ethiopia
France
Gabon
Gambia
Georgia
Ghana
Greece
Guatemala
Guinea
Guinea-Bissau
Guyana
Honduras
Hungary
Iceland
India
Israel
Jamaica
Japan
Jordan
Kazakhstan
Kenya
Kyrgyzstan
Lao People's Democratic Republic
Latvia
Lesotho
Liberia
Luxembourg
Macedonia
Madagascar
Malawi
Malaysia
Mali
Mauritania
Mexico
Mongolia
Morocco
Mozambique
Namibia
Nepal
Netherlands
Nicaragua
Niger
Nigeria
Norway
Pakistan
Panama
Papua New Guinea
Paraguay
Peru
Philippines
Portugal
Romania
Russia
Rwanda
Senegal
Sierra Leone
Slovakia
South Africa
Spain
Suriname
Swaziland
Sweden
Switzerland
Tajikistan
Tanzania
Thailand
Timor-Leste
Togo
Trinidad and Tobago
Tunisia
Turkey
Uganda
Ukraine
United Arab Emirates
United Kingdom
United States
Uruguay
Uzbekistan
VietNam
Yemen
Zambia

Appendix C: Data Requirements as presented to data collectors in Spring 2010

System overview

- What organizations are involved in water quality monitoring in any way
  - What organizations are involved in operational monitoring
  - Surveillance monitoring
  - Compliance monitoring
- What are the responsibilities and activities of these different organizations
- How do these organizations interact
- How many scenarios exist within the country (a scenario is a distinct monitoring approach, for Ghana there are ~3 scenarios. Scenario 1 was GWCL/AVRL monitoring the 82 largest population centers. Scenario 2 was CWSA/District Assemblies monitoring small towns and point sources. Scenario 3 was compliance or surveillance monitoring
- Are different source types and distribution methods monitored differently (or are other distinctions used, such as treated/untreated, rural/urban, or population size).

Quantitative costing parameters (each data need below applies to EACH scenario)

- Frequency of testing

- How many sites are tested
- How many laboratories exist
- Type of personnel and number of each personnel involved in monitoring activities including:
- Sampling
- Testing (sample analysis)
- Data write up and reporting (information management)
- Oversight (generally there is a water quality manager or director at both regional and national level)
- Lab locations (if there are plant labs vs. regional labs, differentiate which are which)
- Type of transit used for sample collection
- Distance travelled for each site (averaging using spatial data etc)
- Current testing device used for field and lab

Impact parameters (each data need below applies to EACH scenario)

- Who receives information (does information stay within agencies, or is it shared and reported on)
  - In what format do they receive information (report, data table, unorganized results)
  - How are results generated (who is involved in interpreting, compiling, reporting data)
  - How long after results are generated do they reach recipients

- Is information used in decision making
- If so, who is responsible for making decisions regarding water quality measures

Data for modeling

- How many population centers fall under each scenario (i.e. which towns are supplied by which water supplier, which towns have what type of water source and distribution, what is the population of various towns, etc)
- What is the range/fractions of different source and distribution system type

Appendix D: Interview Guidelines as presented to data collectors in Spring 2010

Note: *The following is a set of guidelines for conducting an interview. The main purpose of any interview is to fulfill the data needs outlined in a separate document. These data needs need to be filled in a comparable fashion in every country. Some data points require validation, or need to be collected separately from different organizations. Thus, the interview template below can be adjusted when necessary to fill the data needs completely and accurately.*

Template for Standardized Interview

Introduction

a. Thank you:
   - "First I would like to thank you for taking the time to talk to me today, we are very happy to be working in (Ghana), and it's always nice to have local support"

b. Introduction:
   - "Hi, my name is (Jonny Crocker), I am a researcher from the Water Institute at UNC, and my background is (in environmental engineering). Here is my card for future reference. (We got your name from (GWCL managing director) while talking to them earlier this week.)"

c. Project Description:
   - "(I know you have a copy of the letter from our program director already, but I'd like to still start with a quick description of the project before we go into talking about water quality monitoring here in (Ghana)). This project involves looking at how water quality monitoring is conducted in a variety of countries from around the world, including, of course (Ghana). We are looking specifically at microbial water quality, and specifically at drinking water. So for example Ecoli, coliform, and chlorine testing in water supplies. This project involves researching policies and standards related to WQM, but also actual implementation of monitoring, and how the resulting information is used and reported on. We have already talked to (GWCL, GSB, and CWSA), but are hoping to get some information on how (AVRL) is involved."

General overview and layout questions

d. Organizations involved

- "Could you talk a little bit about what organizations in (Ghana) are involved in WQM in any way?

  Follow up, clarification questions (*Note: only need to ask these questions in the first 2-3 meetings in a country)*

  - Does this include organizations or agencies that are involved in setting policies? Standards? Regulations? Oversight or surveillance?
  - Are there (other) private organizations or companies that carry out some part of monitoring? (Such as doing laboratory analysis)
  - Is the ministry for health (department of health, whatever it is in (Ghana)) involved in any way in monitoring?

e. Interactions between organizations

- "How do the different organizations you mentioned interact with each other?"

  Follow up, clarification questions (*Note: exact questions to be used should be catered to the organization being interviewed)*

  - Do all organizations that do monitoring do their own sampling? Analysis of samples? Recording and reporting of water quality results? Or are there some cases where one group will for example take a sample, and take it to someone else's lab?
  - Do any of these organizations interact or collaborate in setting policies, regulations, or standards?
  - Does this organization report to any other organization or agency? Is there any organization that is responsible for oversight or surveillance of water supplied by this provider?
  - Does this organization oversee any of the water suppliers or other organizations?

f. Monitoring activities

- What are the roles and activities of these different organizations in water quality monitoring in (Ghana)? *(Note: this question only to be asked 2-3 times, during the first few meetings in a country)*
- What is the role and what are the activities of (organization being interviewed) in water quality monitoring in (Ghana)?

  Follow up for high level government agencies (ministry for health, ministry of water resources, etc)

  - About policy, regulation, creation and amendment of policy and regulation.

  Follow up for water providers

  Follow up for oversight and regulatory groups

  - Does (organization) conduct any testing?
    - If so, what microbial tests do they do, and what laboratories do they use. After these tests are done, what happens with the results? Who are these results reported to, and happens after reporting?
    - If not, who reports test information to (organization)? How is the quality of these tests determined?
    - Frequency of testing, frequency of reporting, method for enforcement, format for reporting
  - If there is a specific way that (organization) is involved in oversight or regulation of water quality in (country), is this documented anywhere?

  Follow up for laboratory or testing groups (public or private)

g. Regulations and frameworks for monitoring

End of meeting

h. Thank you
   - Once again, thank you for discussing water quality monitoring with me today. The information you have shared will be helpful as we work to learn about monitoring practices around the world, and what works best.

i. Ask for further contacts (*Note: what contacts you will ask for will depend on what meetings have already occurred, and which organization you are currently referring to. Try to obtain multiple interviews within each organization)*
   - As you know, I am hoping to talk to a number of different organizations while I am in (Ghana). Do you possible know anybody (at organization, in city, etc) who would be able to talk to me while I am here?

j. Ask for documents *(Note: this could come before or after asking for contacts, depending on what seems most appropriate. No need to collect duplicates of documents from multiple sources)*
   - Policies
   - Regulations
   - Standards, methods
   - Frameworks
   - Manuals
   - Records of water quality
   - Reports on water quality (especially important when these have some ties to decision making, enforcement, or any other kind of response to information on water quality)

Any variations or different terminology for the above

Appendix E: Data and methods used in cost analyses

Country		
Scenario		
Parameter	Value	Method

India - Uttar Pradesh

Community-Based Rural Monitoring

# tests (practice)	12,223	Based on interview account that 10% of IMIS database data comes from this scenario
# tests (theory)	4,400,000	From interview, 2 tests per source per year for 2,200,000 rural sources is the goal
type of test	H2S Presence-Absence	From interview, and observation of laboratory capabilities
test materials cost ($/test)	$0.62	Taken from Kromoredjo and Fujioka (1991). Estimate assumes vials are reused and excludes tranport costs.
labor cost	$0.00	All activities are performed voluntarily
sample transport cost (rs/sample)	$0.00	Community-based teams test water supply in their community, with no transport necessary

Laboratory-Based Rural Monitoring

# tests (practice)	110,000	From interview stating that 100,000 to 120,000 test are run per year (~5% of sources)
# tests (theory)	220,000	From interview, 10% of sources tested once per year is the goal
type of test	H2S Presence-Absence	From interview, and observation of laboratory capabilities
test materials cost ($/test)	$0.62	Taken from Kromoredjo and Fujioka (1991). Estimate assumes vials are reused and excludes tranport costs.
lab staff cost ($/test)	$1.10	Based on interview account from West Bengal

sampling staff wage ($/hour)	$0.25	Assumes an annual pay of $500 for MPWs, who are gram panchayat level employees.
sampling staff time (hrs/sample)	1.6	assumes a sampler collects 5 samples in an average day (based on observations of sampling in low-density areas of Jordan)
sample transport cost ($/sample)	$2.67	Value derived from West Bengal guidance document

Small Urban Monitoring

# tests (practice)	0	From interviews
# tests (theory)	57,240	Based on CPHEEO manual and population data from census
type of test	Multiple Tube/MPN	From interview, and observation of laboratory capabilities
test materials cost ($/test)	$1.62	Taken from Kromoredjo and Fujioka (1991). Estimate assumes vials are reused and excludes tranport costs.
lab staff cost ($/test)	$1.10	Based on interview account from West Bengal
sampling staff wage ($/hour)	$0.25	Assumes an annual pay of $500 for MPWs, who are gram panchayat level employees.
sampling staff time (hrs/sample)	0.8	assumes a sampler collects 10 samples in an average day (twice as many as samplers for lower density rural monitoring scenarios)
sample transport cost ($/sample)	$2.67	Value derived from West Bengal guidance document

Large Urban Monitoring

# tests (practice)	546	Based on hardcopy recorded results for 1 week, scaled up to 52 weeks.
# tests (theory)	10,284	Based on CPHEEO manual and population data from census
type of test	Multiple Tube/MPN	From interview, and observation of laboratory capabilities

test materials cost ($/test)	$1.62	Taken from Kromoredjo and Fujioka (1991). Estimate assumes vials are reused and excludes tranport costs.
lab staff cost ($/test)	$1.10	Based on interview account from West Bengal
sampling staff wage ($/hour)	$0.25	Assumes an annual pay of $500 for MPWs, who are gram panchayat level employees.
sampling staff time (hrs/sample)	0.8	assumes a sampler collects 10 samples in an average day (twice as many as samplers for lower density rural monitoring scenarios)
sample transport cost ($/sample)	$2.67	Value derived from West Bengal guidance document

India - West Bengal

Rural Monitoring

# tests (practice)	103,894	Record of tests for 6 months was taken obtained, and scaled to 12 months
# tests (theory)	940,536	From interview, 2 tests per source per year. Assumes 123 people per source, which is the average of the Maharashtra and Uttar Pradesh
type of test	Multiple Tube/MPN	From interview, and observation of laboratory capabilities
test materials cost ($/test)	$1.62	Taken from Kromoredjo and Fujioka (1991). Estimate assumes vials are reused and excludes tranport costs.
lab staff cost ($/test)	$1.10	Based on interview account from West Bengal
sampling staff wage ($/hour)	$0.25	Assumes an annual pay of $500 for MPWs, who are gram panchayat level employees.
sampling staff time (hrs/sample)	1.6	assumes a sampler collects 5 samples in an average day (based on observations of sampling in low-density areas of Jordan)
sample transport cost ($/sample)	$2.67	Value derived from West Bengal guidance document

Small Urban Monitoring

# tests (practice)	944	Assumes all 236 towns in census that are not covered by large urban monitoring are included here. Each town tested 4x per year per town frm interview
# tests (theory)	19,171	Based on CPHEEO manual and population data from census
type of test	Multiple Tube/MPN	From interview, and observation of laboratory capabilities
test materials cost ($/test)	$1.62	Taken from Kromoredjo and Fujioka (1991). Estimate assumes vials are reused and excludes tranport costs.
lab staff cost ($/test)	$1.10	Based on interview account from West Bengal
sampling staff wage ($/hour)	$0.25	Assumes an annual pay of $500 for MPWs, who are gram panchayat level employees.
sampling staff time (hrs/sample)	0.8	assumes a sampler collects 10 samples in an average day (twice as many as samplers for lower density rural monitoring scenarios)
sample transport cost ($/sample)	$2.67	Value derived from West Bengal guidance document

Large Urban Monitoring

# tests (practice)	11,129	Based on compliance of Kolkata from interview, extrapolated to the other major cities
# tests (theory)		Based on CPHEEO manual and population data from census
type of test	Multiple Tube/MPN	Both MPN and Membrane Filtration used, MPN used for unit costs
test materials cost ($/test)	$1.62	Taken from Kromoredjo and Fujioka (1991). Estimate assumes vials are reused and excludes tranport costs.
lab staff cost ($/test)	$1.10	Based on interview account from West Bengal

sampling staff wage ($/hour)	$0.25	Assumes an annual pay of $500 for MPWs, who are gram panchayat level employees.
sampling staff time (hrs/sample)	0.8	assumes a sampler collects 10 samples in an average day (twice as many as samplers for lower density rural monitoring scenarios)
sample transport cost ($/sample)	$2.67	Value derived from West Bengal guidance document

India - Maharashtra

Rural Monitoring

# tests (practice)	1,200,000	two accounts indicated each source is tested 4X per year, or each MPW collects 10 samples per year. These give # of tests of 1,200,000 and 1,416,360. Lower number used here
# tests (theory)	1,200,000	From interview, 4 tests per source per year for 300,000 rural sources is the goal
type of test	Multiple Tube/MPN	From interview, and observation of laboratory capabilities
test materials cost ($/test)	$1.62	Taken from Kromoredjo and Fujioka (1991). Estimate assumes vials are reused and excludes tranport costs.
lab staff cost ($/test)	$1.10	Based on interview account from West Bengal
sampling staff wage ($/hour)	$0.25	Assumes an annual pay of $500 for MPWs, who are gram panchayat level employees.
sampling staff time (hrs/sample)	1.6	assumes a sampler collects 5 samples in an average day (based on observations of sampling in low-density areas of Jordan)
sample transport cost ($/sample)	$2.67	Value derived from West Bengal guidance document

Small Urban Monitoring

# tests (practice)	34,662	online database showed on average complete compliance among all cities. This number is then based on CPHEEO guidelines and population data from Maharashtra
# tests (theory)	34,662	Based on CPHEEO manual and population data from census
type of test	Multiple Tube/MPN	From interview, and observation of laboratory capabilities
test materials cost ($/test)	$1.62	Taken from Kromoredjo and Fujioka (1991). Estimate assumes vials are reused and excludes tranport costs.
lab staff cost ($/test)	$1.10	Based on interview account from West Bengal
sampling staff wage ($/hour)	$0.25	Assumes an annual pay of $500 for MPWs, who are gram panchayat level employees.
sampling staff time (hrs/sample)	0.8	assumes a sampler collects 10 samples in an average day (twice as many as samplers for lower density rural monitoring scenarios)
sample transport cost ($/sample)	$2.67	Value derived from West Bengal guidance document

Large Urban Monitoring

# tests (practice)	25308	online database showed on average complete compliance among all cities. This number is then based on CPHEEO guidelines and population data from Maharashtra
# tests (theory)	25308	Based on CPHEEO manual and population data from census
type of test	Multiple Tube/MPN	From interview, and observation of laboratory capabilities
test materials cost ($/test)	$1.62	Taken from Kromoredjo and Fujioka (1991). Estimate assumes vials are reused and excludes tranport costs.

lab staff cost ($/test)	$1.10	Based on interview account from West Bengal
sampling staff wage ($/hour)	$0.25	Assumes an annual pay of $500 for MPWs, who are gram panchayat level employees.
sampling staff time (hrs/sample)	0.8	assumes a sampler collects 10 samples in an average day (twice as many as samplers for lower density rural monitoring scenarios)
sample transport cost ($/sample)	$2.67	Value derived from West Bengal guidance document

Jordan

Miyahuna - Amman

# tests, distribution system (practice)	1,114	Based on a 2.5 year actual record of tests completed
# tests, sources, treatment plants, pump stations, reservoirs (practice)	4,938	Based on a 2.5 year actual record of tests completed
# tests, distribution system (theory)	408	Based on JISM Standard 286, and population data from the 2008 census
# tests, sources, treatment plants, pump stations, reservoirs (theory)	5982	Based on guideline documents for Miyahuna 2010
type of test	Multiple Tube/MPN	From interview, and observation of laboratory capabilities
test materials cost ($/test)	$1.62	Taken from Kromoredjo and Fujioka (1991). Estimate assumes vials are reused and excludes tranport costs.
# samplers	5	From interview
% of sampler time	20%	Based on number of samples collected for non-biological tests
sampling staff salary	$5,949	Assumes samplers are paid a "semi-professional/technician" salary, taken from 2008 Jordan Census
# lab staff	17	From interview
% lab staff time	10%	Based on observations
lab staff salary	8194	Assumes lab staff are paid a "professional" salary, taken from 2008 Jordan Census

travel distance (miles/sample)	9.41	Assumes the ~17 samples collected each day require 160 miles of travel
cost per mile	$0.35	Adjusted from AAA mileage calculator (gas, maintenance, and depreciation included; insurance and ownership costs excluded)

Aqaba Water Company - Aqaba Governorate

# tests (practice)	540	Based on JISM Standard 286, and population data from the 2008 census
# tests (theory)	540	Based on JISM Standard 286, and population data from the 2008 census
type of test	Multiple Tube/MPN	From interview, and observation of laboratory capabilities
test materials cost ($/test)	$1.62	Taken from Kromoredjo and Fujioka (1991). Estimate assumes vials are reused and excludes tranport costs.
sampling staff cost	530.76	Scaled from Miyahuna scenario using number of tests
lab staff cost	1212.31	Scaled from Miyahuna scenario using number of tests
transportation cost	1823.75	Scaled from Miyahuna scenario using number of tests

Water Authority of Jordan

# tests (practice)	25,000	Based on interview account (# tests would be
# tests (theory)	14,518	Based on JISM Standard 286 and population data from the 2008 census
type of test	Multiple Tube/MPN	From interview, and observation of laboratory capabilities
test materials cost ($/test)	$1.62	Taken from Kromoredjo and Fujioka (1991). Estimate assumes vials are reused and excludes tranport costs.
sampling staff cost	530.76	Scaled from Miyahuna scenario using number of tests

lab staff cost	1212.31	Scaled from Miyahuna scenario using number of tests
transportation cost	1823.75	Scaled from Miyahuna scenario using number of tests

Ministry of Health

# tests (practice)	16,944	Based on JISM Standard 286 and population data from the 2008 census
# tests (theory)	16,944	Based on JISM Standard 286 and population data from the 2008 census
type of test	Multiple Tube/MPN	From interview, and observation of laboratory capabilities
test materials cost ($/test)	$1.62	Taken from Kromoredjo and Fujioka (1991). Estimate assumes vials are reused and excludes tranport costs.
sampling staff cost	530.76	Scaled from Miyahuna scenario using number of tests
lab staff cost	1212.31	Scaled from Miyahuna scenario using number of tests
transportation cost	1823.75	Scaled from Miyahuna scenario using number of tests